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AN EVALUATION OF THE EXTENT AND MAGNITUDE OF BIOLOGICAL EFFECTS ASSOCIATED WITH CHEMICAL CONTAMINANTS IN SAN FRANCISCO BAY, CALIFORNIA

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NOTICE

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ABSTRACT

Chemical contaminants occur throughout all parts of the San Francisco Bay estuary. The potential for these chemicals to cause harm to the biota of the estuary is dependent upon a complex variety of biological and chemical factors. Information on the presence of these chemicals in the water, sediment, or organisms of the estuary alone cannot be used to assume that the chemicals are causing harm to the biota. Empirical measures of adverse effects must be made to provide perspective as to the biological significance, if any, of the chemicals.

Measures of adverse biological effects associated with chemical contaminants in the San Francisco Bay estuary have been quantified and reported by a number of investigators. However, none of these studies was performed with the intent of evaluating the spatial extent and magnitude of adverse effects throughout the entire estuary. In this report three independent approaches were taken to estimate the extent and magnitude (severity) of biological effects associated with toxicants throughout the San Francisco Bay estuary. The first involved an evaluation of the combined data from 60 reports on sediment toxicity to determine which areas had been most and least toxic. The second involved an analysis of newly collected sediment toxicity data from a synoptic survey performed for the National Oceanic and Atmospheric Administration (NOAA) throughout much of the estuary; and, an identification of sites in which sediments were toxic. The third involved a brief review of reports in which a variety of other measures of effects associated with toxicants were reported for San Francisco Bay. The sediment toxicity data provided the maximum spatial resolution in estimates of the geographical extent of effects and the biological measures in resident fish provided the greatest ecological significance in estimates of severity of effects.

The incidences of many different kinds of biological effects observed in the estuary were significantly higher than in other areas along the Pacific Coast. Sediments collected throughout the estuary were found to be toxic to a variety of invertebrates in laboratory tests. Water samples also were toxic to invertebrate larvae. Several bottom-dwelling fish have been observed with elevated incidences of lesions and other histopathological disorders in their internal organs. The enzymatic defense mechanisms in some of these species were induced at elevated levels and the reproductive success was lowered in association with high concentrations of toxicants in the tissues. In addition, the incidences of abnormal nuclei in the blood cells of one species (starry flounder) were significantly elevated. Measures of physiological stress in resident mussels were very high. Seasonal mortalities in striped bass and a gradual decline in the population size has been recorded in the Sacramento-San Joaquin system.

The uneven levels of effort in quantification of different measures of effects in the bay, a lack of data from some areas, and variability in results from different tests and measures of effects in some areas precludes the delineation of those areas in the estuary that are exclusively the most toxic areas. However, in some areas that have been studied in multiple surveys with different types of measures of effects, most of the measures of effects were elevated above conditions in other areas in the bay or with respect to reference conditions outside the estuary. These areas include: the Sacramento-San Joaquin

Delta/Suisun Bay/Carquinez Strait area; Castro Cove near Richmond; the Oakland Inner-Middle-Outer Harbors/San Leandro Bay area; parts of South Bay between the Oakland Bay Bridge and the San Mateo Bridge, particularly in the vicinity of the Port of San Francisco, Hunters Point, and Islais Creek; and Guadalupe Slough, adjacent to the southern portion of South Bay below the Dumbarton Bridge. In some areas, only a few of the measures of effects were elevated relative to other areas, suggesting moderately toxic conditions: Richmond Harbor, Central Bay off the Berkeley/Emeryville shore, and parts of South Bay between the San Mateo Bridge and the Dumbarton Bridge. Most (but, not all) of the data suggest that biological effects were least frequent or least severe in southwestern San Pablo Bay. There were very little or no data available with which to evaluate Richardson Bay, most of San Pablo Bay, the Golden Gate area, and much of Central Bay.

CHAPTER 1
INTRODUCTION

OBJECTIVES AND RATIONALE

The objective of this report was to assess the spatial extent and magnitude (severity) of measures of adverse biological effects associated with chemical contaminants in San Francisco Bay. Chemical contaminants potentially toxic to marine and estuarine organisms have been detected and quantified in the sediments and biota of San Francisco Bay (Davis *et al.*, 1990; Long *et al.*, 1988; Phillips, 1987). These chemicals have the potential to be harmful to valued marine resources of San Francisco Bay if they occur in sufficiently high concentrations and are bioavailable (Phillips, 1987).

Evidence has accumulated from a number of different studies that adverse biological effects associated with toxic chemicals occur in San Francisco Bay biota. Studies of resident starry flounder (*Platichthys stellatus*) have shown relatively high tissue concentrations of some organochlorine compounds, relatively high enzymatic activities in the livers, and reduced reproductive success in some individuals caught near Berkeley and Oakland (Spies *et al.*, 1988). *P. stellatus* caught near Berkeley, Vallejo, and Oakland generally had higher levels of enzymatic activity than those caught at sites outside San Francisco Bay (Spies *et al.*, 1990; Long and Buchman, 1990).

An investigation of staghorn sculpin (*Leptocottus armatus*) showed relatively high levels of hepatic enzymatic activity at some sites near Castro Cove (Spies, 1989a). Liver and kidney lesions in a number of species of fish caught near Hunters Point, Oakland, and other locations in the estuary have been observed and reported (Varanasi *et al.*, 1988; Carrasco *et al.*, 1990). The incidence of micronuclei in the erythrocytes (blood cells) of one species of fish (*P. stellatus*) caught at several sites in the estuary were significantly higher than the incidence in the same species caught outside the estuary (Long and Buchman, 1990). Periodic seasonal mortalities and a long-term, gradual decline in the population of striped bass (*Morone saxatilis*) in the Sacramento-San Joaquin river system have been documented (Brown *et al.*, 1987); toxic effects of chemicals may be among the factors affecting this species of fish.

Water samples collected in a number of locations throughout the estuary proved to be toxic to invertebrates in laboratory toxicity tests (Anderson *et al.*, 1990). Relatively high toxicity was observed in the initial toxicity tests performed with sediments collected in the estuary. Sediment samples from some peripheral areas, such as Islais Creek and near Hunters Point (Chapman *et al.*, 1987; U.S. Navy, 1987) and some areas in South Bay (Baumgartner, unpublished manuscript) proved to be toxic to invertebrates.

The data from these different studies, collectively, provide substantial evidence that toxicant-related effects occur among at least some of the resident biota of the estuary. However, the available data preclude an identification of the spatial patterns in toxicant-associated effects with a high degree of spatial resolution. The data are from analyses of either highly mobile fish, transient water masses, or small numbers of samples. Substantially more data available from numerous sediment toxicity tests, if merged, could provide needed information on the spatial extent of toxicant-associated effects. The approach taken in this report was to assemble as much data as possible from different investigations to piece together an estimate of the extent and severity of effects.

Chemical analyses of water, sediment, and/or biota alone provide no evidence of harmful biological effects. To provide perspective as regards the biological significance of the chemicals, measures of effects are needed. These measures of effects can include death, reduced reproductive success, abnormal morphology, elevated induction of defense mechanisms, altered behavior, altered abundance, and altered composition of resident biological communities. The data can be generated in studies performed in field investigations or laboratory experiments.

POTENTIAL FOR TOXICITY

The sediment chemistry data available from numerous studies performed throughout much of the estuary indicated that the peripheral harbors and channels (Figure 1) are generally more highly contaminated than the basins (Long *et al.*, 1988). The average concentrations of six trace metals and three groups of organic compounds in selected regions reported by Long *et al.* (1988) are summarized in Table 1. In their data evaluation, Long *et al.* (1988) included harbors, ship channels, marinas, and industrial waterways around the perimeter of the estuary as "peripheral" areas. Relatively small differences were apparent in average concentrations among the three basins; but, the selected peripheral areas often had substantially higher contaminant concentrations than the basins. When the averages for all basin samples combined and all peripheral samples combined were compared (Table 2), there appeared to be a general trend of higher average concentrations in the periphery than in the basins, particularly for Ag, Cu, Pb, sum of seven PAH, tDDT, and tPCB. However, the differences in concentrations are relatively small for some toxicants (*e.g.*, Hg and Cd). Unexpectedly, the average concentrations of some chemicals were slightly higher in the basins than in peripheral areas (*e.g.*, Cr and sum of 18 PAH). The high variability in concentrations was reflected in the large standard deviations for each category. Based upon these chemical data, a similar pattern in sediment toxicity would be expected. That is, average toxicity should be slightly higher in the periphery than in the basins. However, there may be considerable small-scale patchiness and variability in toxicity.

Table 1. Mean concentrations of selected toxicants in surficial sediments from three basins and four peripheral areas of San Francisco Bay (from Long *et al.*, 1988). Trace metal data are expressed in ppm dry weight and organic compound data in ppb dry weight. No data are noted as ND.

	Basins			Periphery			
	San Pablo Bay	Central Bay	South Bay	Oakland Inner Harbor	Islais Creek Harbor	Redwood Creek	Richmond Harbor
Trace Metals							
Hg	0.45	0.35	0.65	0.57	1.30	0.42	0.40
Cd	0.71	0.79	1.44	0.67	2.23	2.47	0.65
Cu	45	33	33	72	78	66	36
Pb	32	34	30	97	102	87	39
Cr	280	81	84	ND	140	91	123
Ag	0.45	0.72	0.57	ND	4.69	ND	ND
Organic Compounds							
tPAH*	2600	3900	2700	7200	62700	ND	ND
tDDT	9	16	3	120	3	ND	260,700
tPCB	27	71	28	361	305	ND	ND

* Sum of 18 individual PAH.

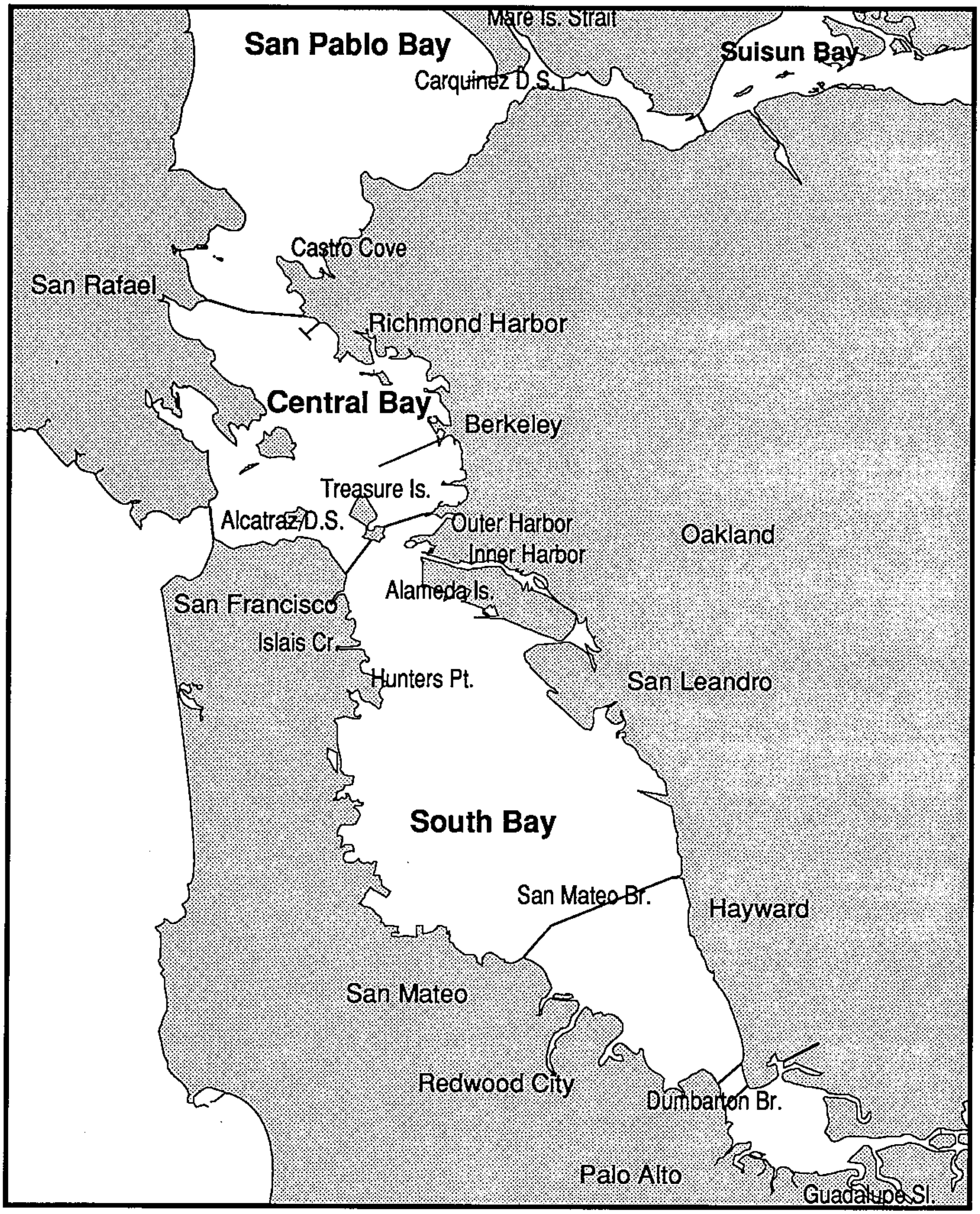

Figure 1. San Francisco Bay Estuary.

Table 2. Overall average concentrations (± standard deviations) of selected toxicants and numbers of samples tested in basin and peripheral areas (from Long *et al.*, 1988). Trace metal data are expressed in parts per million (ppm) dry weight, organic compound data in parts per billion (ppb) dry weight.

Chemical	All Basins	All Periphery
Trace Metals		
Hg	0.45 ± 0.73, n =396	0.52 ± 0.63, n = 701
Cd	0.94 ± 1.25, n = 256	1.10 ± 1.13, n = 743
Cu	36 ± 22, n = 376	62 ± 73, n = 503
Pb	32 ± 27, n = 461	69 ± 371, n = 853
Cr	108 ± 129, n = 140	80 ± 70, n = 256
Ag	0.51 ± 0.51, n = 148	1.63 ± 1.83, n = 188
Organic Compounds		
Σ 18 PAH*	2700 ± 2700, n = 11	2480 ± 39,100, n = 10
Σ 7 PAH**	1600 ± 1400, n = 77	12,200 ± 18,700, n = 24
tDDT	9 ± 15, n = 75	190 ± 380, n = 78
tPCB	45± 35, n = 37	287 ± 245, n = 15

* Sum of 18 individual PAH compounds (from Figure 72, Long *et al.*, 1988).

** Sum of seven individual PAH compounds (from Table 29, Long *et al.*, 1988).

These data provide information on the spatial patterns in the concentrations of these chemicals but provide no insight as regards the potential for toxicity. No biological data were acquired to accompany the chemical measures in most of the studies. No sediment quality criteria have been developed thus far to use in assessing these data. To provide informal guidelines for use in the evaluation of data from the NS&T Program, Long and Morgan (1990) examined data from a number of different technical approaches and geographic locations and determined the ranges in chemical concentrations often associated with toxic effects. For each of a number of trace metals and organic compounds, they determined Effects Range-Low (ERL) and Effects Range-Median (ERM) values. The ERL values were interpreted as being the concentrations at which toxic effects may be first observed. The ERM values were interpreted as the concentrations often or always associated with toxic effects in a number of independent studies.

To estimate which areas in the San Francisco Bay estuary may have the highest potential for toxic effects, the ambient sediment chemistry data summarized by Long *et al.* (1988) were compared with the ERL and ERM values for nine chemicals (Figures 2 through 10). In Figures 2 through 7, the minimum, median, and maximum concentrations of the selected chemicals are shown for many regions in the estuary, based upon data merged from a number of individual studies, and compared with the ERL and ERM values. In Figures 8 through 10, the average concentrations of the chemicals at specific sampling sites are compared with the ERL and ERM values. The studies in which these chemical data were generated often did not include biological measurements of effects.

In this evaluation, areas are assumed to have the highest potential for toxic effects where ambient chemical concentrations exceed the ERM values by large factors and where many chemicals exceed the ERM values. The potential for toxic effects is assumed to be moderate where the ERL values are exceeded, but the ERM values are not. The potential for toxic effects is assumed to be relatively low where the ERL values are not equalled or exceeded. These conclusions must be tempered by site-specific factors (*e.g.*, acid volatile sulfide, organic carbon, grain size, mineralogy) that can affect the bioavailability and toxicity of sediment-associated chemicals.

The minimum concentrations of silver in all areas and the median concentrations in most areas did not equal or exceed the ERL value (1.0 ppm) for silver (Figure 2). However, the concentrations of silver in China Basin and Islais Creek (both along the southern San Francisco shoreline) were very high (medians of 5.3 and 4.0 ppm and maxima of 16.0 and 9.0 ppm, respectively). Both of these median concentrations exceeded the ERM value. The maximum concentration in China Basin exceeded the ERM value (2.2 ppm) by a factor of 7. The potential for toxicity in China Basin and Islais Creek could be relatively high. Also, the maximum concentrations were relatively high in Mare Island Strait and Oakland Outer Harbor. Within the estuary, the areas with the lowest silver concentrations included Suisun Bay, San Pablo Bay, and Central Bay.

The concentrations of cadmium in all regions of the estuary were relatively low compared to the effects range of Long and Morgan (1990) (Figure 3). None of the minimum or median concentrations equalled or exceeded the ERL value (5 ppm) for cadmium. Among the regions that had the lowest cadmium concentrations were Castro Cove, Hunters Point, Point Molate, Central Bay, and San Pablo Bay. The maximum concentration (17.3 ppm) in South Bay exceeded the ERM by a factor of less than 2; none of the other maxima exceeded or equalled the cadmium ERM value (9 ppm). Sediments from Mare Island Strait, Coyote Creek, Islais Creek, and China Basin exceeded the ERL value, but not the ERM value.

In contrast to cadmium, chromium occurs in many regions of San Francisco Bay in relatively high concentrations (Figure 4). The median chromium concentration in San Pablo Bay (190 ppm) exceeded the ERM value (145 ppm) and the maximum concentration there (769 ppm) exceeded the ERM by a factor of about 5. Some samples from Islais Creek, Mare Island Strait, South Bay, and Central Bay also had relatively high chromium concentrations that exceeded the ERM value. Areas in which the median chromium concentrations did not equal or exceed the ERL value (80 ppm) included: Guadalupe Slough, Castro Cove, San Leandro Bay, and South Bay.

Maximum copper concentrations in most regions of the estuary exceeded the ERL value (70 ppm), but none exceeded the ERM value (390 ppm) (Figure 5). The highest copper concentration (293 ppm) occurred in China Basin. The median concentrations in China Basin, Oakland Inner Harbor, and San Leandro Bay exceeded the ERL value. Regions in which the median concentrations were well below the ERL value included South Bay, Central Bay, Richmond Harbor, and Carquinez Strait/Suisun Bay.

Lead concentrations in China Basin were extremely high (Figure 6); the median (339 ppm) exceeded the ERM (110 ppm) and the maximum concentration (2,580 ppm) was about 23 times higher than the ERM value. Also, some samples from Oakland Inner Harbor, Islais Creek, and San Pablo Bay had relatively high concentrations of lead. The median concentrations in many areas equalled or exceeded the ERL value (35 ppm). Regions in which the median concentrations were below the ERL value included: Central Bay, Gallinas Creek, San Pablo Bay, Coyote Creek, South Bay, Carquinez Strait/Suisun Bay, and Castro Cove.

None of the median concentrations from any of the regions exceeded the ERM value (1.3 ppm) for mercury. However, some sediment samples from Coyote Creek, Islais Creek, Guadalupe Slough, and South Bay had relatively high mercury concentrations, the maxima exceeding the ERL value by factors of about 5 (Figure 7). The median concentrations in most areas were slightly higher than the ERL value (0.15 ppm). Relatively low median mercury concentrations occurred in San Pablo Bay, Central Bay, and Carquinez Strait/Suisun Bay.

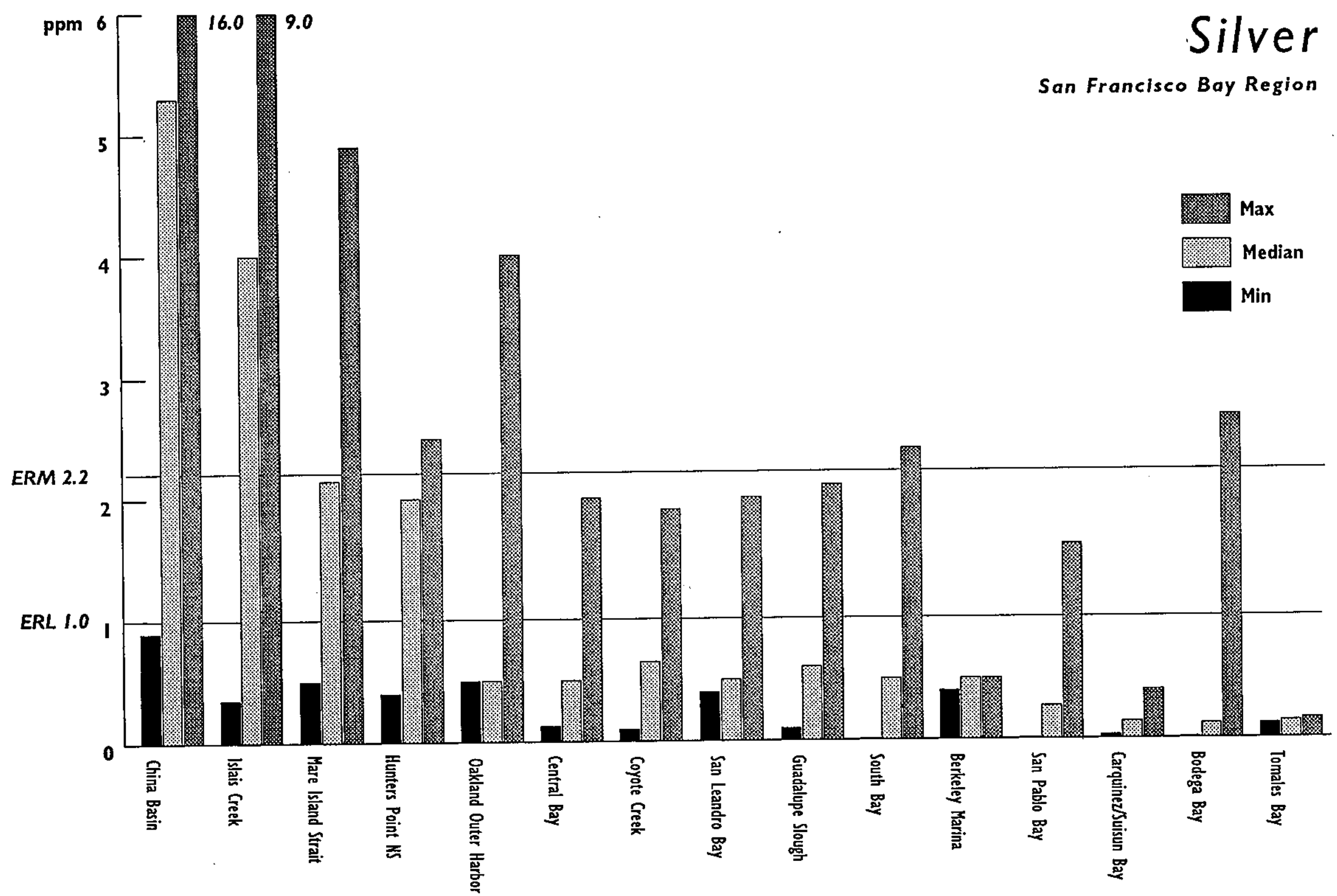

Figure 2. Minimum, median, and maximum silver concentrations in regions of San Francisco Bay (from Long *et al.*, 1988) and ERL and ERM value: for silver (from Long and Morgan, 1990).

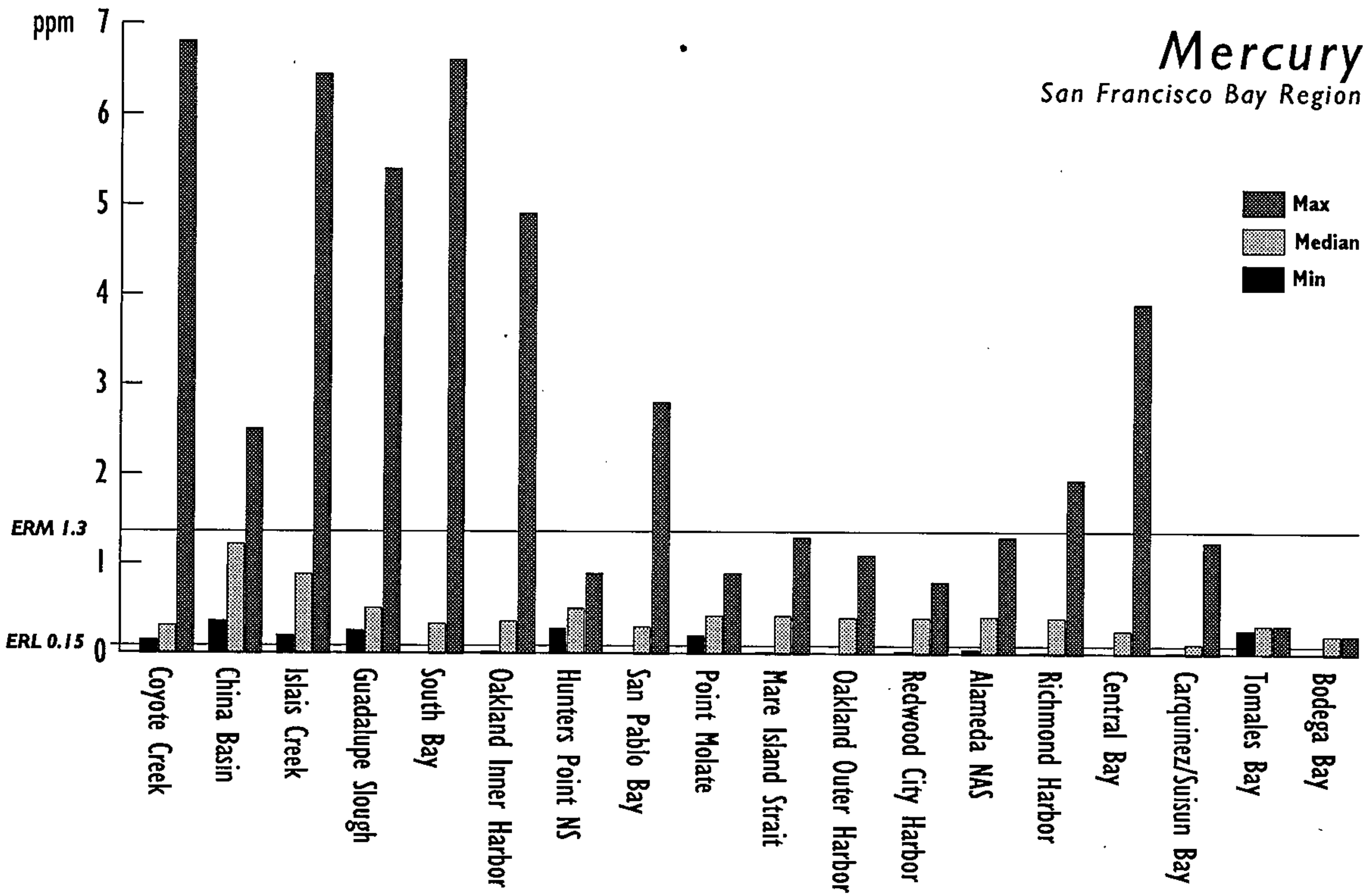

Figure 3. Minimum, median, and maximum mercury concentrations in regions of San Francisco Bay (from Long *et al.*, 1988) and ERL and ERM values for mercury (from Long and Morgan, 1990).

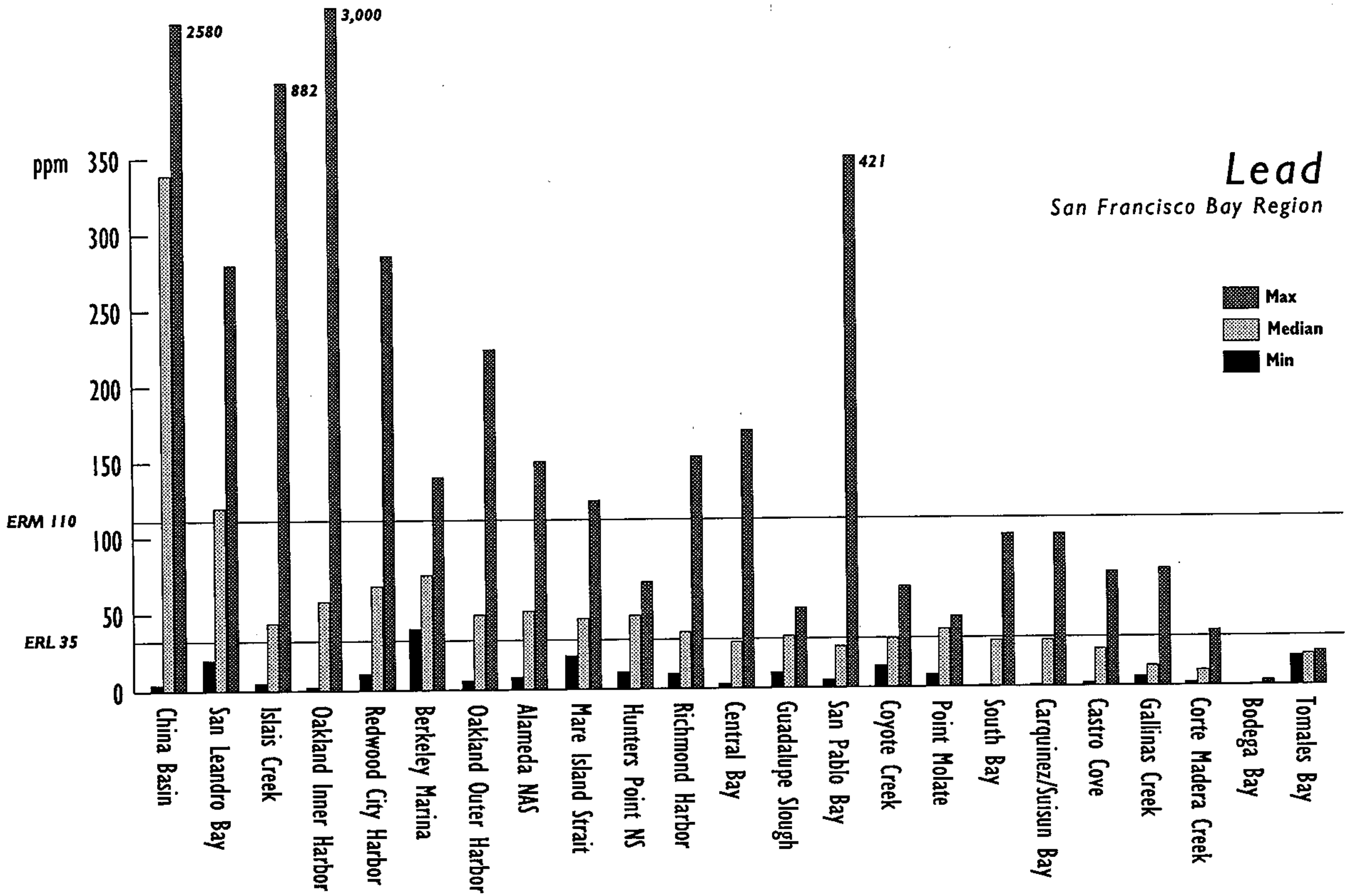

Figure 4. Minimum, median, and maximum lead concentrations in regions of San Francisco Bay (from Long *et al.*, 1988) and ERL and ERM values for lead (from Long and Morgan, 1990).

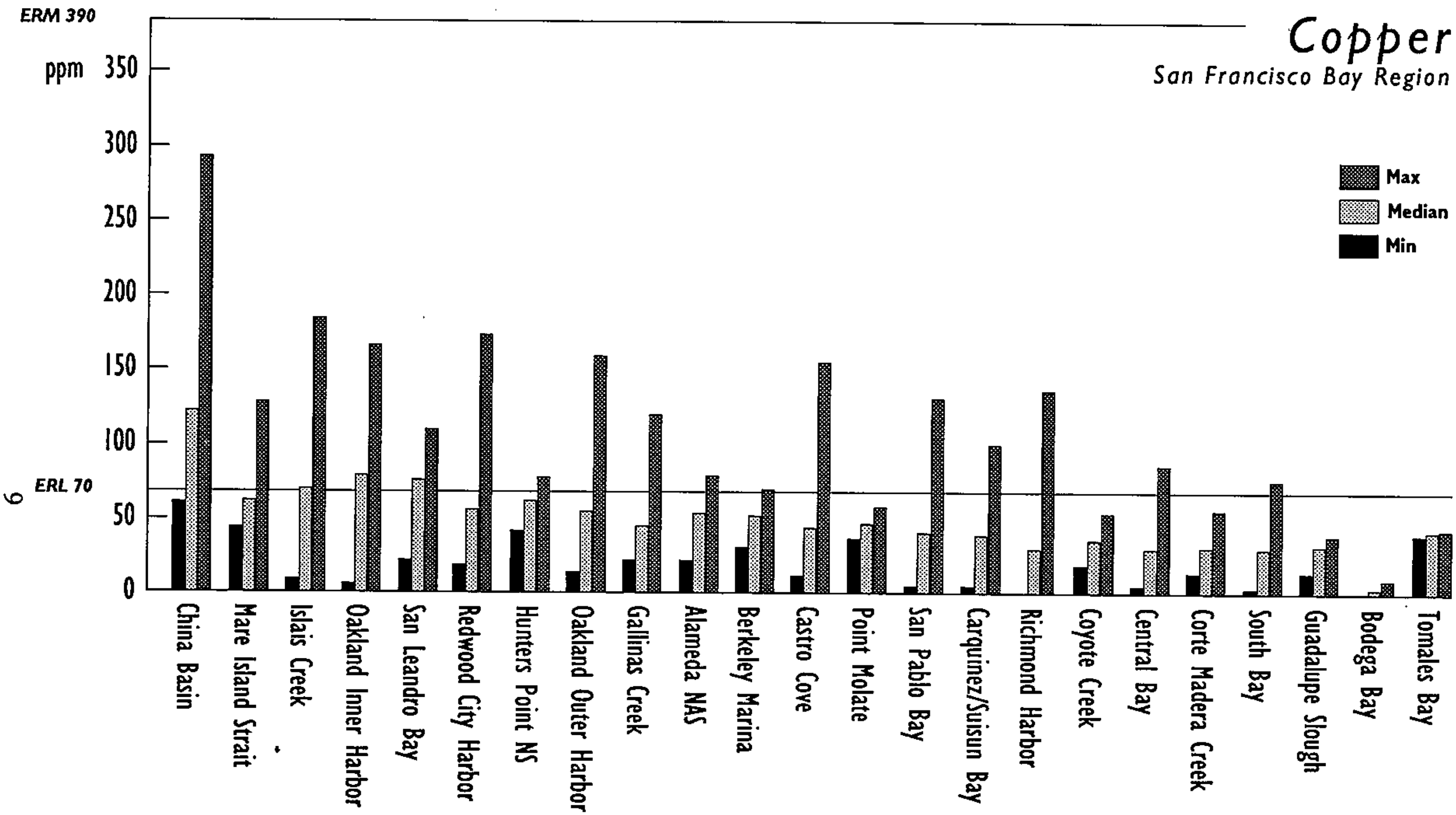

Figure 5. Minimum, median, and maximum copper concentrations in regions of San Francisco Bay (from Long *et al.*, 1988) and ERL and ERM values for copper (from Long and Morgan, 1990).

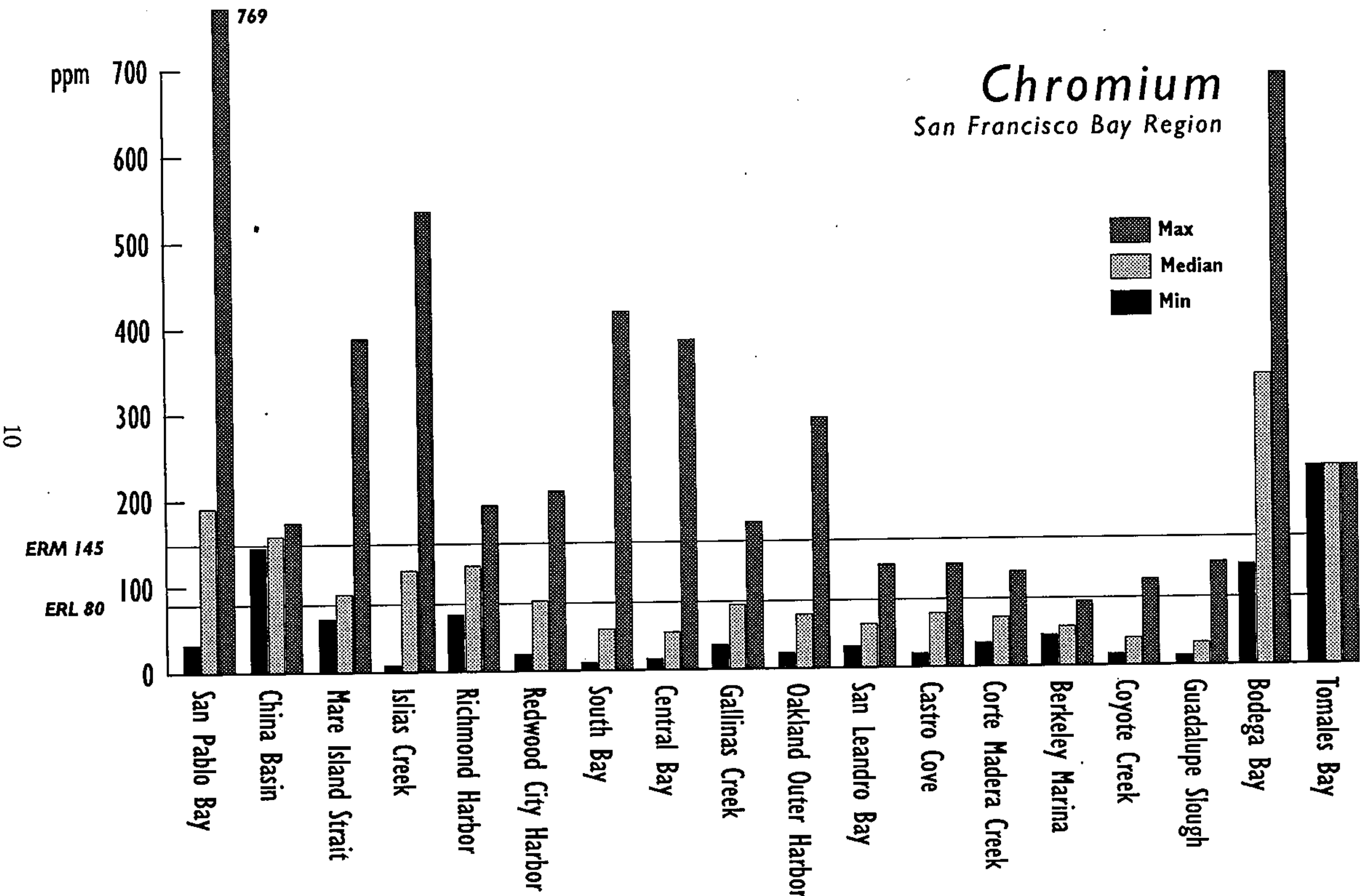

Figure 6. Minimum, median, and maximum chromium concentrations in regions of San Francisco Bay (from Long et *al.*, 1988) and ERL and ERM values for chromium (from Long and Morgan, 1990).

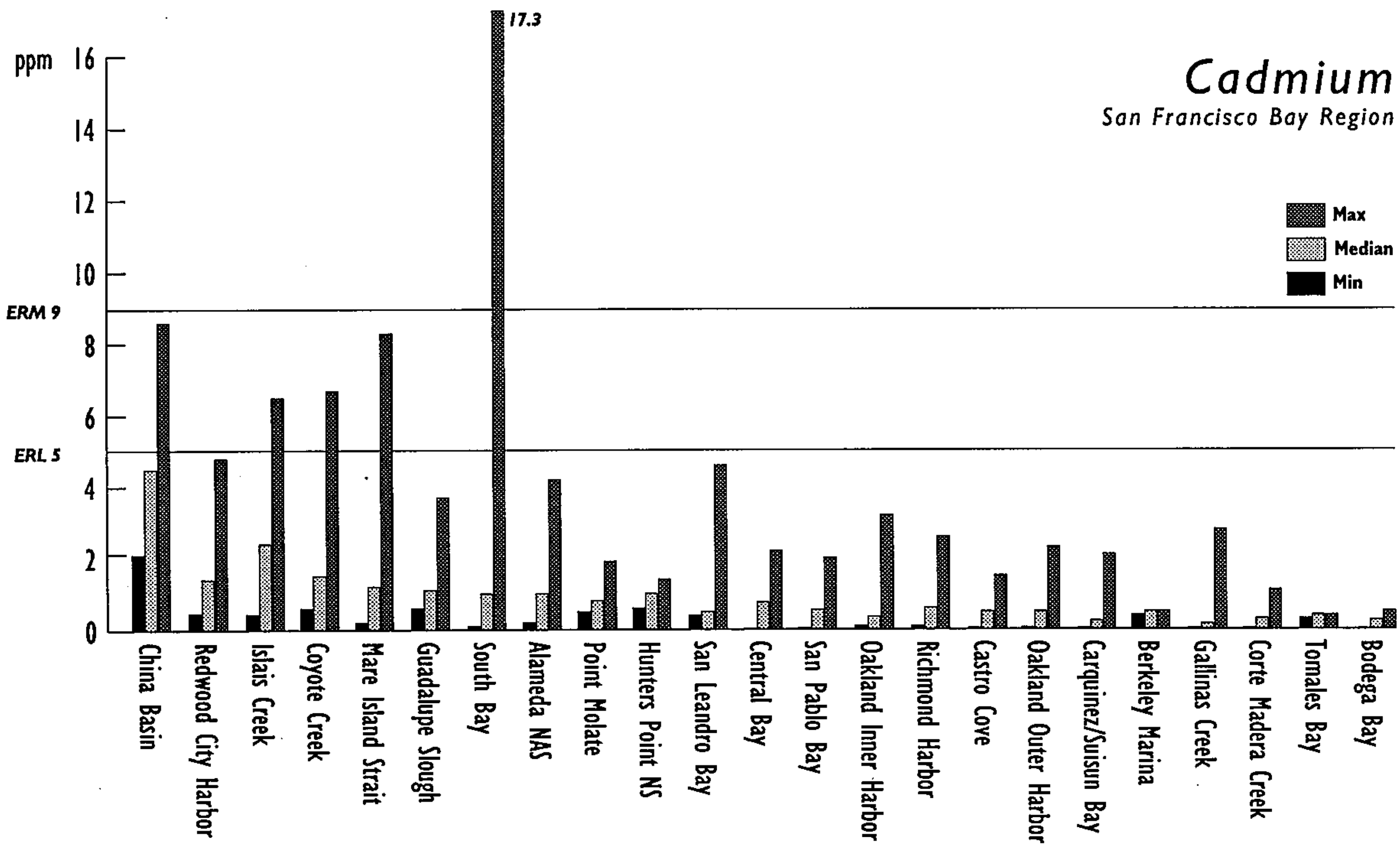

Figure 7. Minimum, median, and maximum cadmium concentrations in regions of San Francisco Bay (from Long *et al.*, 1988) and ERL and ERM values for cadmium (from Long and Morgan, 1990).

Insufficient data were available for most organic compounds to warrant merging data and determining minima, maxima, and medians for regions of the bay (Long *et al.*, 1988). Therefore, the data were listed as average concentrations for individual sampling sites, usually based upon analyses of three samples. The average total of 18 polycyclic aromatic hydrocarbons (tPAH) concentration in an India Basin site equalled the ERM (35 ppm), and the average in an Islais Creek site (132 ppm) exceeded the ERM (Figure 8). Also, tPAH concentrations were relatively high in sites sampled in China Basin and Oakland Middle Harbor, but did not exceed the ERM value. Sites in which the tPAH concentration did not equal or exceed the ERL value (4.0 ppm) included: San Mateo Bridge, Hunters Point, Alameda Naval Air Station (NAS), Yerba Buena Island, Berkeley, Southhampton Shoal in Central Bay, Richmond, and San Pablo Bay.

Total poychlorinated biphenyls (tPCB) concentrations were highest in sites sampled in India Basin, Islais Creek, and Oakland Inner Harbor; equalling or exceeding the ERM value of 400 ppb (Figure 9). At many of the sites, the PCB concentrations did not equal or exceed the ERL value of 50 ppb: average concentrations were lowest at sites sampled in San Pablo Bay, in Central Bay at Southhampton Shoal, and off the Alameda NAS.

Total dichlorodiphenyltrichloroethane (tDDT) concentrations were extremely high in Lauritzen Canal at the head of Richmond Harbor, the average concentration (260,700 ppb) exceeded the ERM value (350 ppb) by a factor of about 750 (Figure 10). Elsewhere, the DDT concentrations were low relative to the ERM value and often did not exceed the ERL value of 3 ppb.

In summary, exceedances of the chemical concentrations previously associated with toxicity were most frequent in many of the peripheral harbors. However, some exceedances also occurred in some sediments from the basins. The concentrations of these nine chemicals exceeded the respective ERM values most frequently in Islais Creek, China Basin, South Bay, Mare Island Strait, Oakland Outer Harbor, San Pablo Bay, Richmond Harbor, and Central Bay. The potential for toxicity would be greatest in sediments from these areas. Exceedances of ERL values, but not ERM values, were most frequent in Islais Creek, Mare Island Strait, China Basin, Richmond Harbor, Oakland Inner Harbor, and Central Bay. The chemical concentrations in all of these areas, except the Oakland Inner Harbor, also exceeded a number of ERM values. The potential for toxicity probably would be moderate in the Oakland Inner Harbor. Among these nine chemicals, those that could have the highest potential to induce toxicity included silver, chromium, lead, and mercury, since the concentrations of these chemicals often exceeded the concentrations associated with toxicity. Areas where chemical concentrations often did not exceed the ERL values included Tomales Bay, Bodega Bay, Berkeley Marina, San Pablo Bay, Central Bay, off the Alameda NAS, and off Hunters Point.

The data evaluated in Figures 2 through 10 demonstrate the patchiness in chemical concentrations within all of the regions of the estuary. Within all of these regions, some samples had very low chemical concentrations that probably posed little potential for toxicity and other samples taken nearby had extremely high concentrations of the same chemical or of other chemicals that could have been extremely toxic. Some the sediments collected in the basins, that in general had lower average concentrations of most chemicals (Tables 1 and 2), have had high concentrations of some chemicals in at least some of the samples. The significance of this heterogeneity is that samples from many regions of the estuary could have potential for toxicity. An exceedance of any single toxicological threshold could result in a toxic response in a laboratory test.

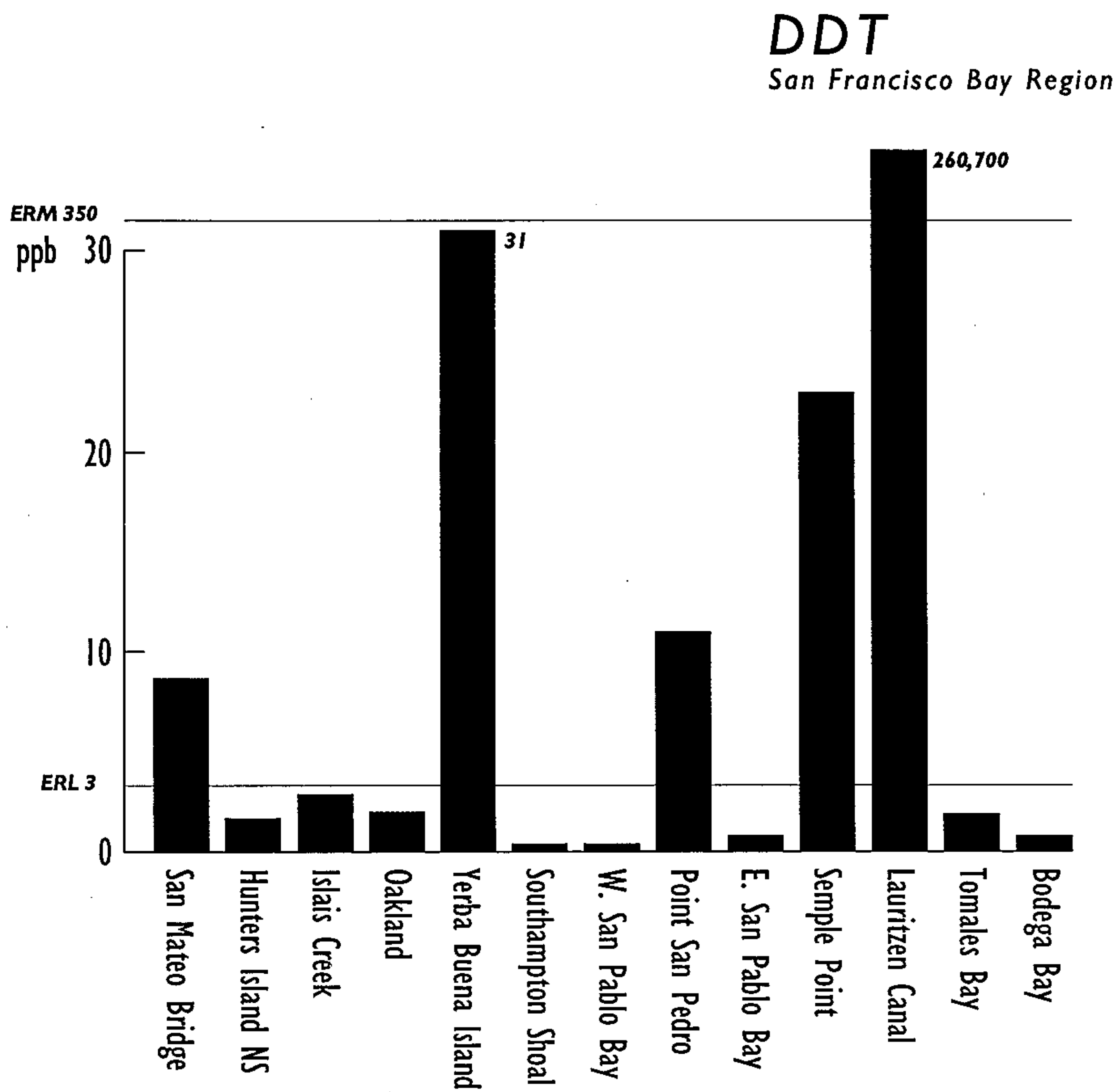

Figure 8. Mean tDDT concentrations at specific sampling sites in San Francisco Bay (from Long et *al.*, 1988) and ERL and ERM values for tDDT (from Long and Morgan, 1990).

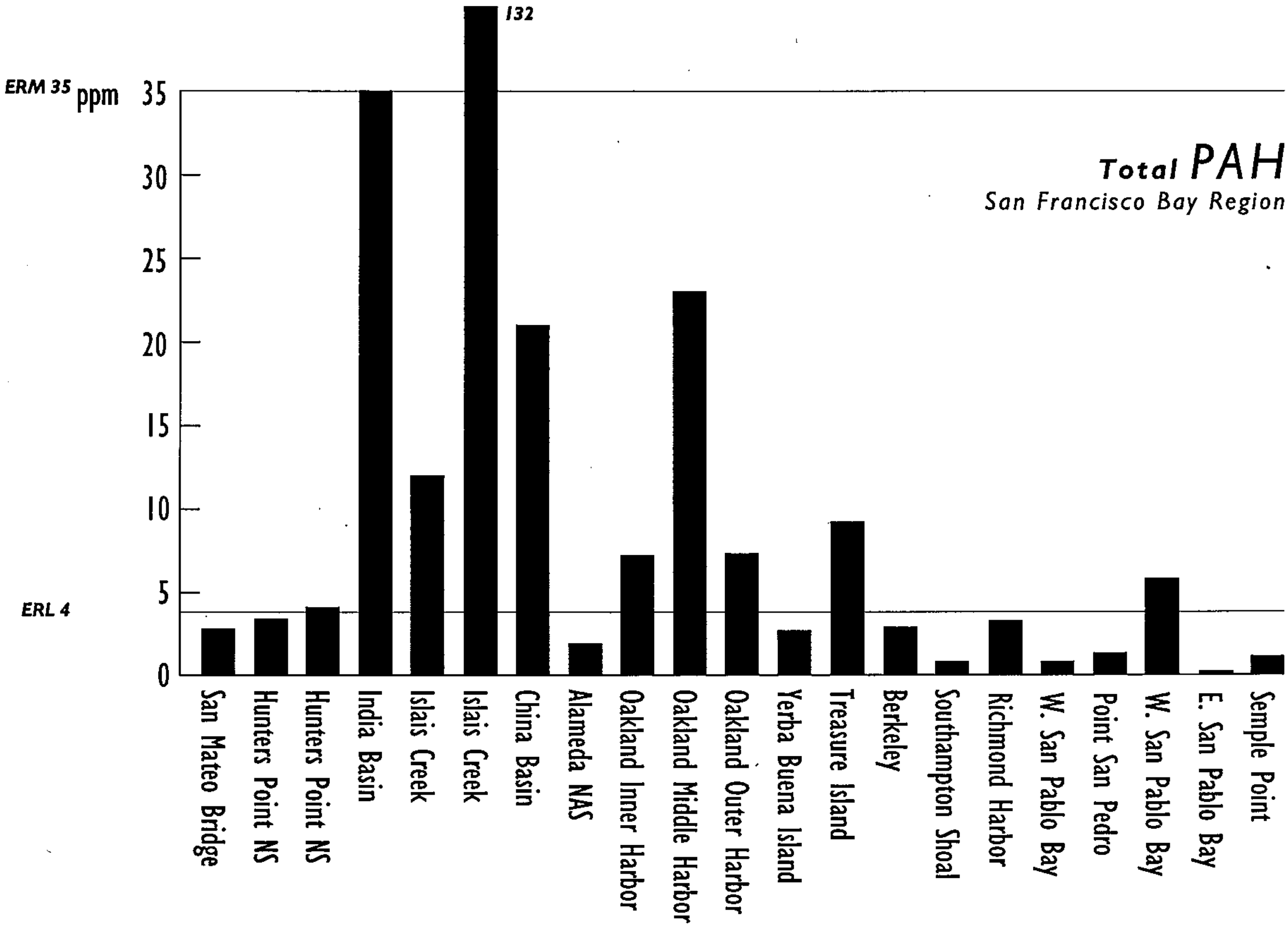

Figure 9. Mean tPAH concentrations (sum of 18 compounds) at specific sampling sites in San Francisco Bay (from Long *et al.*, 1988) and ERL and ERM values for tPAH (from Long and Morgan, 1990).

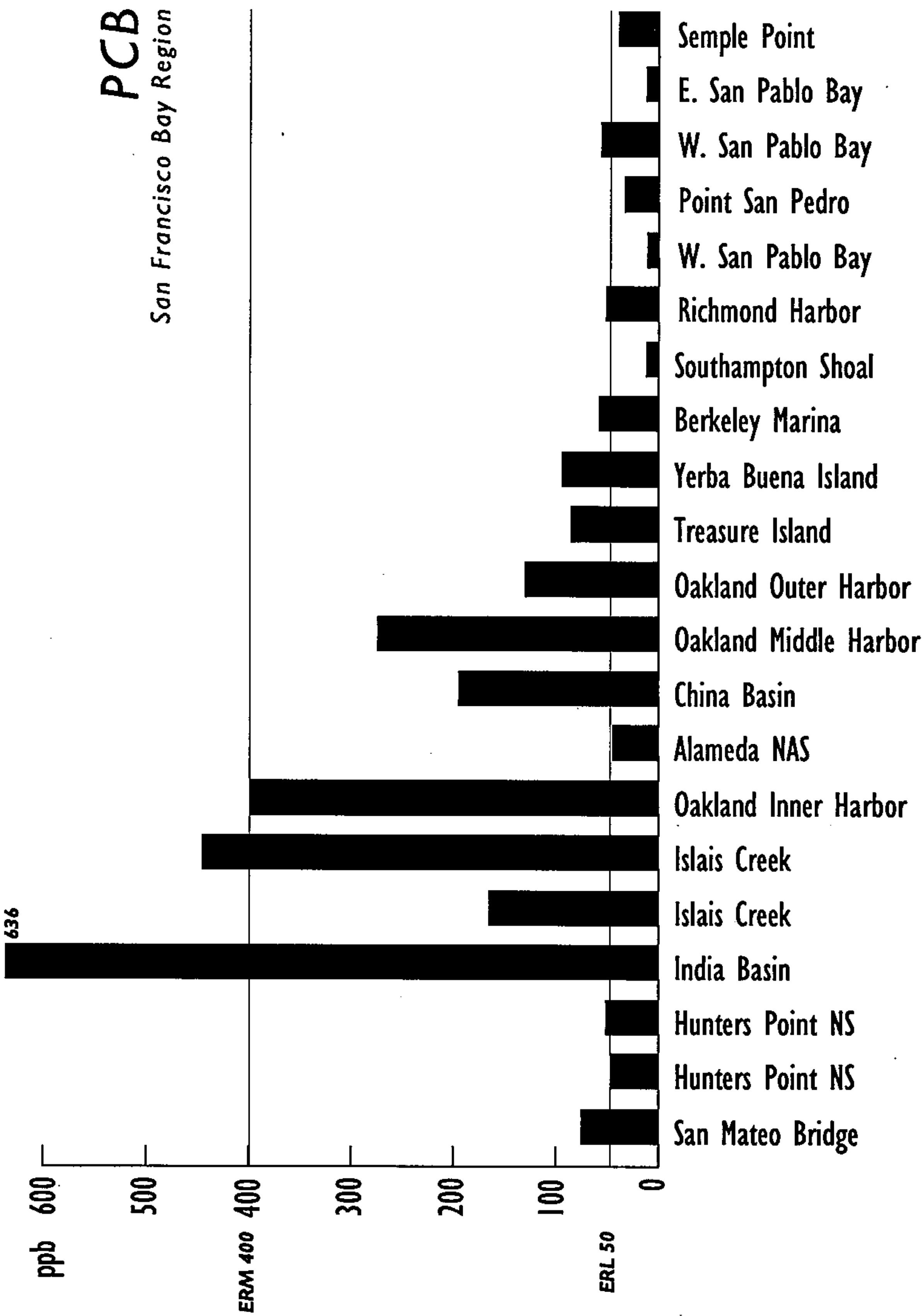

Figure 10. Mean tPCB concentrations at specific sampling sites in San Francisco Bay (from Long et al., 1988) and ERL and ERM values for tPCB (from Long and Morgan, 1990).

The data in Figures 2 through 10 illustrate that the chemical concentrations throughout the estuary often approximate the levels commonly associated with toxicity. Given these chemical concentrations, subtle changes in bioavailability caused by shifts in sediment properties could cause potentially different results in toxicity tests. For example, many regions of the estuary have median mercury concentrations that approximate the ERL value for mercury or lie within the ERL-ERM range. These mercury concentrations are sufficiently high to warrant concern that they may cause toxicity. Subtle differences between regions in sulfide content or texture could result in differences in toxicity. For example, regions with high mercury content, but with correspondingly high concentrations of sulfides and fine-grained particles, may not be toxic if the mercury is not available.

OVERALL APPROACH

The data summarized above suggest that, overall, average chemical concentrations often are higher in some peripheral harbors than in other areas of the estuary. Also, these chemical concentrations in some samples equal or exceed the levels previously associated with toxicity. Some specific areas in which chemical concentrations were particularly high were identified. However, the data suggest that conditions are very heterogeneous within all regions of the estuary. Therefore, we hypothesized that toxic effects may be most frequent and severe in peripheral areas, but, also may be observed in some of the basins of the estuary less frequently.

The approach taken in this report was to assess the severity and magnitude of biological effects based upon a preponderance of evidence. Chemical contaminants occurring in mixtures can cause a wide variety of biological effects ranging from death to subtle, sublethal changes in physiology or behavior. Therefore, an attempt also was made to summarize the different types of effects associated with toxicants that have been measured in the estuary. Data previously collected by other investigators were summarized along with newly gathered data to piece together an overall picture of biological effects in the estuary. The biological data that were sought for review were those for which there was a likely relationship with toxicants and which could be evaluated to estimate the spatial extent of incidence within the estuary.

The largest single collection of similar data indicative of biological effects associated with toxicants in San Francisco Bay was that formed from studies of sediment toxicity. Sediments can provide an integrated record of contaminant accumulation and they are relatively immobile. Many samples of sediments have been collected throughout the estuary, often in dense sampling grids, and tested for toxicity. Therefore, these data, collectively, should provide the finest spatial resolution of the extent of toxic effects. However, since these data were generated from laboratory tests, they provided little information on the ecological significance of toxic effects among resident biota. The review of these toxicity data is described in chapter 2. In addition, the results of a 1990 synoptic survey of sediment toxicity sponsored by NOAA are reported in chapter 3. Data generated from measures of adverse effects in resident feral fish provide the greatest ecological significance, but because these animals are mobile and because only a relatively small number of sites were sampled for each measure, the spatial resolution in these data is relatively poor. Brief reviews of many measures of bioeffects in resident fish are provided in chapter 4, along with data from tests of water and mussels. Chapter 5 is a summation of the evidence from these independent studies described in the preceeding chapters.

The data reviewed and presented in this report are a mixture of subjective and objective observations. In chapter 2, the incidence of statistically significant results are compared among regions of the estuary as an estimate of the spatial extent of toxicity. In addition, the average numerical results in each region are compared as an estimate of the severity of toxicity. In chapter 3, sampling sites are identified in which toxicity was significantly higher than in respective controls. In chapter 4, significant results were identified when provided by the authors of the reports that were reviewed. The densities of the data and the sampling designs differed among these studies. Therefore, the summation of these data in chapter 5 is necessarily a mixture of subjective and objective observations described in the preceding chapters.

CHAPTER 2

A SUMMARY OF HISTORICAL SEDIMENT TOXICITY DATA

INTRODUCTION

Data available from a small number of studies of sediment toxicity in San Francisco Bay have been summarized (Long *et al.*, 1988; Davis *et al.*, 1990; Phillips, 1987). Since those summary reports were published, many more studies have been completed. All of the recent studies individually involved relatively small portions of the bay. No syntheses of similar data have been performed thus far to identify large-scale patterns in toxicity. The objective of the evaluation performed in this chapter was to determine baywide spatial patterns in sediment toxicity, based upon data merged from many different historical surveys. Also, an attempt was made to determine some of the relationships among toxicity and physical-chemical parameters.

Methods and Data Availability

Data were available from 60 different studies listed in Appendix A. These studies of sediment toxicity in San Francisco Bay were performed by several laboratories, for many different sponsors, and in many different geographic regions of the estuary. Most of the data were developed during pre-dredging studies. Therefore, most of the data have been generated for the peripheral waterways and harbors of the estuary. For example, one of the toxicity tests was performed with 143 samples collected in peripheral areas and from only 18 samples collected in the basins of the estuary.

A number of different larval invertebrates, adult invertebrates, and fish have been used in sediment toxicity tests performed in the estuary. The majority of the data were from suspended phase bioassays in which the embryos of either the oyster *Crassostrea gigas* or the mussel *Mytilus edulis* were used. The amount of data available from solid phase bioassays using the amphipod *Rhepoxynius abronius* also is relatively large, but smaller than that available from the bivalve mollusk tests. Therefore, the evaluation of historical data was restricted primarily to the data from these two types of tests. Additional data from a relatively small number of tests performed with the amphipods *Eohaustorius estuarius* and *Hyalella azteca* and the embryos of the sea urchin *Strongylocentrotus purpuratus* were available and were considered.

The data from the 60 reports were entered into a spreadsheet, summarized, and evaluated to determine geographic patterns in toxicity. Data from bioassays in which *C. gigas* or *M. edulis* were used were merged and treated as though they were equivalent. Data from performance of undiluted samples (*i.e.*, 100% sediment/water suspensions) were treated separately from those data generated in bioassays of diluted samples (*i.e.*, 50% suspensions).

Data from different studies performed in the same geographic regions using the same methods were merged to determine severity and geographic patterns in toxicity. The major regions for which data exist are illustrated in Figure 1. The basins of the estuary for which data exist include San Pablo Bay, Central Bay, and South Bay. The South Bay basin was further divided into a northern part between the Oakland Bay Bridge and the San Mateo Bridge, a central part between the San Mateo Bridge and the Dumbarton Bridge, and a southern part below the Dumbarton Bridge. The peripheral areas of the estuary included Richmond Harbor, Mare Island Strait, Oakland Harbor, Islais Creek, Guadalupe Slough, refinery docks, the Port of San Francisco shoreline, and other areas either near point sources or in waterways, marinas, and harbors.

In most of the studies, the samples that were significantly different than the respective controls were indicated by the authors, but in many others they were not so indicated or the tests were performed without replication. Consequently, it was not possible to determine spatial patterns in significantly toxic samples versus nontoxic samples with all of the data. Therefore, the data for each region were examined in two different procedures. First, average percent mortality (amphipod tests) or abnormal development (bivalve larvae tests) were calculated and compared. Incidences of exceedances of arbitrary percents of mortality or abnormal development were determined for each region. Second, the incidences of results that were significantly different from respective controls in each survey were determined for each region and compared. The former approach provides information on the magnitude of the toxic response and the second approach provides information on the statistical significance of the data.

Most samples were collected with coring devices and the contents of the core homogenized over the length of the core and with the contents of other cores collected nearby. Therefore, the precision with which geographic patterns could be determined was somewhat diminished as a result of this compositing process. Also, this compositing process precluded determination of the sediment strata(um) in which the toxic agents occurred.

Bivalve embryo test results from the use of the Puget Sound Protocols (Tetra Tech, Inc. and E.V.S. Consultants (1986) and from the U.S. Environmental Protection Agency (EPA)/Army Corps of Engineers (ACOE) (1977) protocols were not merged, but, rather, were treated independently. In both protocols, the sediments were shaken and allowed to settle for a specified period. In the tests performed with the Puget Sound Protocols, the settled sediments remained in the bottom of the exposure chamber during the bioassay; whereas, in the tests conducted with the EPA/ACOE protocols only, the supernatant was used in the bioassay and the settled solids were discarded.

In Appendix A, each evaluated report was assigned a reference number that matches the references listed; and, each report was identified as regards the study name or study area. The sampling dates were listed, along with the station number or designator used in the study, the type of bioassay performed, the average result reported in the study, an indication of whether the station result was statistically significantly more toxic than the respective controls, a designation as to whether the station was a peripheral location or a basin location, and a designation of the geographic region in the estuary in which the samples were collected. A list of region codes is found at the end of Appendix A.

The locations of the sites that have been sampled and tested for toxicity are illustrated in Figure 11. The stars in Figure 11 reflect either individual sampling sites or areas in which many samples have been collected. They do not necessarily reflect the intensity of sampling in some areas that have been sampled repeatedly, but are intended to indicate those general areas in the estuary for which there are sediment toxicity data. The preponderance of sampling in the peripheral waterways relative to the basins of the estuary is illustrated in this figure. The areas that have been frequently sampled include the Alcatraz disposal site, Oakland Inner Harbor, Oakland Outer Harbor, Richmond Harbor, Mare Island Strait, southern South Bay below the Dumbarton Bridge, and along the Port of San Francisco shoreline.

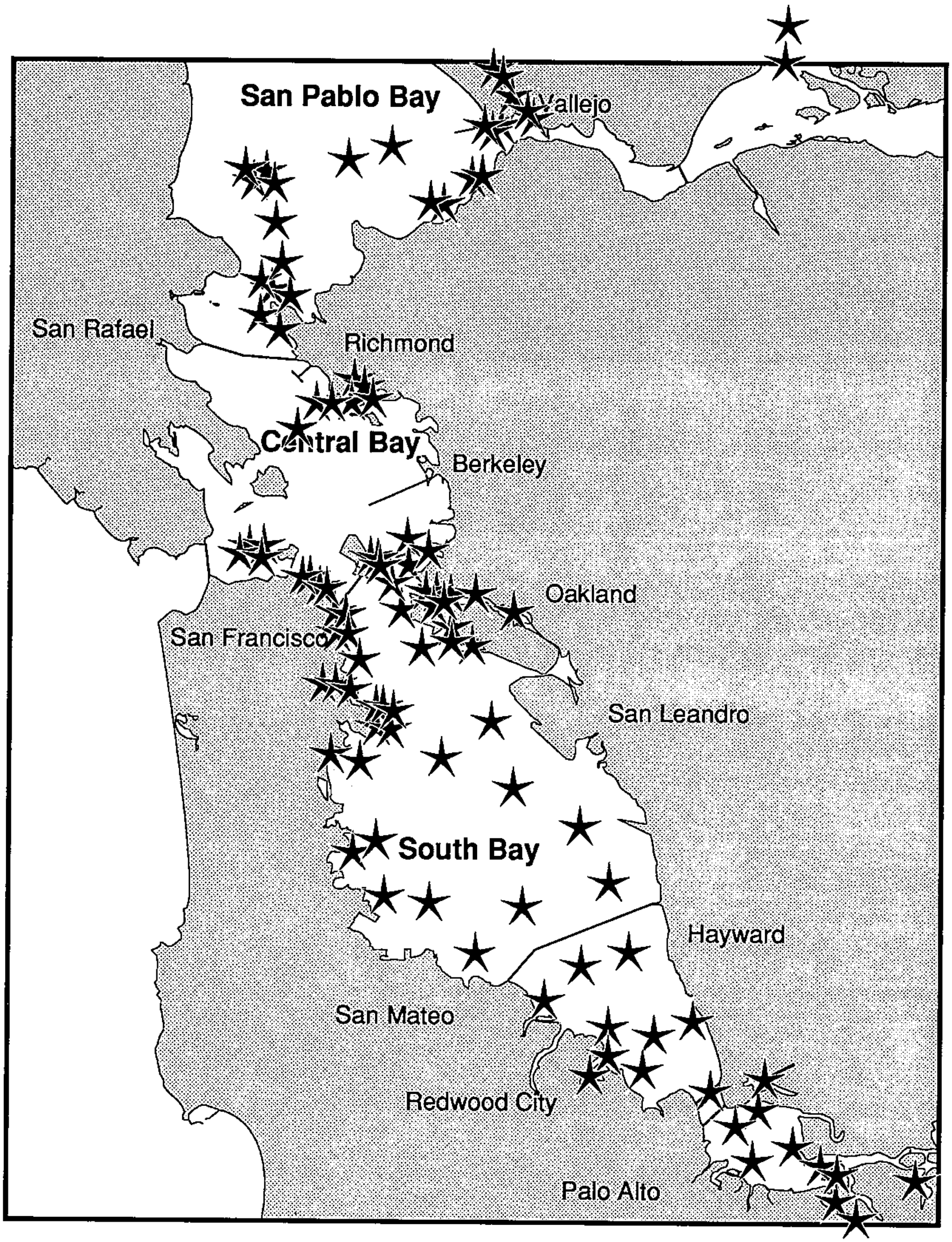

Figure 11. Locations of historical sediment toxicity sampling areas, based upon studies listed in Appendix A.

Large-Scale Patterns in Toxicity

The data from most of the toxicity tests listed in Appendix A are summarized in Table 3. The overall averages (and standard deviations) of the sample means or station means reported are compared among the basins, peripheral areas, and the two dredged material disposal sites that were most frequently tested. In bivalve embryo tests performed with samples diluted 50 percent, 6 samples from the basins had an average of 21.3 percent incidence of abnormalities as compared with 116 samples collected in peripheral areas that had an average incidence of 24.3 percent abnormalities, not a large difference. The average incidence of abnormalities also was similar in samples from both the Alcatraz and Carquinez disposal sites.

Data were available from 198 samples tested in non-diluted (100% sediment/water) suspensions; 57 percent of the samples were toxic. A total of 42 percent (13 of 31) basin samples were significantly toxic versus a total of 62 percent (90 of 144) of the peripheral samples. The average incidence of abnormalities (16.3%) was much lower in the 18 samples from the basins than in 143 samples from the peripheral areas (42.5%) and the Alcatraz and Carquinez disposal sites (35.5% and 57.8%, respectively). These data suggest that the Carquinez disposal site sediments (average of 57.8% abnormalities) were much more toxic than those from the basins.

Data were available from 21 samples tested with bivalve embryos, using the Puget Sound Protocols. Mean percent abnormal development was 3 times higher in 6 peripheral samples than in 15 basin samples. However, average results from the sea urchin tests were similar in both peripheral areas and the Alcatraz disposal site.

Fifty percent (56 of 111) of the samples tested with *R. abronius* were significantly toxic. The average incidences of mortalities were slightly lower in the basin samples (average of 34.2% mortality) than in the peripheral samples (average of 38.8% mortality). A total of 39 percent of the basin samples (13 of 33) were toxic versus 55 percent (43 of 78) of the peripheral samples.

Some recent studies have been conducted in the southern end of South Bay in which sediments have been tested with estuarine and freshwater species of amphipods (*E. estuarius* and *H. azteca*). The data have indicated somewhat higher toxicity in basin samples (average of 54.6% mortality) taken near the Dumbarton Bridge than in peripheral samples (average of 36% mortality) collected in Guadalupe Slough, other adjacent sloughs, and in the discharge channels of sewage treatment plants.

Overall, except for the toxicity tests performed with the amphipods *E. estuarius* and *H. azteca*, there is a repeating pattern of slightly higher toxicity in peripheral areas combined than in basin areas combined. However, this generalization should be viewed with caution, since there are considerably more data from the peripheral areas than from the basins and there is considerable variability in the data within these two geographic categories. The standard deviations for most areas often approximate or exceed the means. Some variability is to be expected since the data from many different parts of the estuary were merged to generate the averages. Also, average percent mortality and abnormality data do not account for relative viability of test organisms in the controls.

Small-Scale Patterns in Toxicity

In Tables 4, 5, and 6 the averages of the percent mortality in *R. abronius* bioassays and of percent abnormal development in bivalve embryo bioassays are compared among the basins, disposal sites, and specific peripheral areas. Based upon the average results, each area was also ranked in order of descending toxicity. Also, the sample sizes available from each area are shown.

Table 3. Average percent incidence of abnormalities in bivalve embryos (three testing protocols), average percent successful fertilization of sea urchin embryos, and average percent mortalities in three species of amphipods, based upon data merged from 60 reports listed in Appendix A.

Region	Bivalve % abnormal 50% dilution	Bivalve % abnormal no dilution	Bivalve % abnormal Puget Sound Protocols	Sea Urchin %fertilization no dilution	*R. abronius* % mortalities	*E. estuarius*/ *H. azteca* % mortalities
All Basins	21.3 ± 20.6 n = 6	16.3 ± 29.3 n = 18	12.9 ± 4.9 n = 15		34.2 ± 21.3 n = 56	54.6 ± 25.1 n = 8*
All Peripherals	24.3 ± 27.4 n = 116	42.5 ± 39.1 n = 143	39.7 ± 31.3 n = 6	85.2 ± 22.2 n = 12	38.8 ± 19.2 n = 63	36.0 ± 21.6 n = 23*
Alcatraz	28.3 ± 24.4 n = 12	35.5 ± 39.3 n = 30		87.6 ± 15.4 n = 4	11.5 ± 13.4 n = 2	
Carquinez	28.1 ± 34.9 n = 6	57.8 ± 39.0 n = 7				

* All tests with *E. estuarius* and *H. azteca* have been performed with sediments collected in the southern end of South Bay.

In addition, in Tables 4 and 6, the ratios (and percentages) of the number of samples tested in each area to the total number that were identified in the original report as significantly more toxic than controls are listed. Again, each area was ranked, based upon these percentages.

Table 4. Results of amphipod toxicity tests for regions in San Francisco Bay based upon data listed in Appendix A. (A) Average percent mortality with standard deviations (and number of samples) among *R. abronius* and area ranks based upon the average mortalities. (B) Ratio (and percentages) of samples identified in tests with *R. abronius, E. estuarius,* or *H. azteca* as significantly more toxic than controls versus the total numbers of samples that were tested and area ranks based upon the ratios.

Geographic Area	(A) Average Mortality (%)	Area Ranks	(B) Ratio of Toxic samples versus total (%)	Area Ranks
BASINS				
South Bay, central part	55.4 ± 22.6 (14)	3	ND	ND
Central Bay	33.3 ± 7.5 (3)	9	3/3 (100%)	1
South Bay, southern part	32.0 ± 14.4 (13)	11	6/12 (50%)	10
South Bay, northern part	25.0 ± 14.3 (9)	13	0/3 (0%)	13
San Pablo Bay	23.4 ± 17.5 (17)	14	4/15 (27%)	11
PERIPHERAL AREAS				
Oakland Outer Harbor	75.5 ± 5.0 (2)	1	2/2 (100%)	1
Castro Cove	60.3 ± 26.5 (3)	2	3/3 (100%)	1
Islais Creek Waterway	52.0 ± 37.8 (3)	4	2/3 (67%)	8
Hunters Point Naval Base	37.2 ± 15.1 (8)	6	6/6 (100%)	1
Oakland Inner Harbor	36.0 ± 17.1 (24)	7	14/25 (56%)	9
Alameda Naval Base	33.5 ± 3.5 (2)	8	2/2 (100%)	1
Southern South Bay channels	33.0 ± 11.4 (9)	10	6/23 (26%)	12
Richmond Harbor	27.0 ± 15.6 (2)	12	2/2 (100%)	1
Guadalupe Slough channel	21.5 ± 3.4 (4)	15	0/4 (0%)	13
Alcatraz disposal site	11.5 ± 13.4 (2)	16	0/2 (0%)	13
Treasure Island Naval Base	48.3 ± 18.3 (6)	5	6/6 (100%)	1

ND indicates no data.

The calculations of average toxicity results (Table 4, column A) allow an evaluation of the magnitude of the effects (mortality or abnormal development). For example, average results of 100 percent mortality in an area suggest a much more toxic condition than an average of, say, 60 percent mortality. However, calculations of average results do not take into account the variation in results of testing the controls in individual surveys. Therefore, data for each area also are shown (Table 4, column B) that indicate the numbers of samples that were significantly different from controls versus the total number of samples that were tested.

The sediments most toxic to *R. abronius* were collected in the Oakland Outer Harbor and Castro Cove (Table 4). Only two and three samples, respectively, were tested in each area; all were significantly more toxic than the respective controls. Fourteen samples from the central part of South Bay (between the San Mateo and Dumbarton bridges) caused relatively high mortality in the amphipods (average of 55.4%), but, since the tests were performed without replication, it was not possible to identify which samples were significantly different from the controls. Two of three samples from Islais Creek Waterway were significantly toxic and average mortality was 52 percent. All three samples collected off Emeryville in Central Bay were significantly toxic, but the average mortality of 33.3 percent ranked ninth. All of the samples from the Hunters Point, Alameda Naval Base, Richmond Harbor, and Treasure Island Naval Base areas were significantly toxic. The area sampled most frequently, the Oakland Inner Harbor, was intermediate in toxicity compared to the other areas. Based upon the average percent mortalities and the percent of the samples that were significantly toxic, the sediments from the following areas were considerably less toxic than other areas in the bay: Alcatraz disposal site, the Guadalupe Slough channel, the other southern South Bay channels (below the Dumbarton Bridge), the northern part of South Bay (between the Oakland Bay Bridge and the San Mateo Bridge), and San Pablo Bay.

The data from some regions were developed in several different surveys performed at different times by different investigators. For example, data were generated for the lower reaches of the Oakland Inner Harbor in two surveys. Average percent mortality among *R. abronius* tested in December 1986 was 62.7 ± 16.3 and all three of the samples were significantly more toxic than controls (reference 7 in Appendix A). In tests performed in March 1988 with *R. abronius*, average percent mortality was much lower(27.2 ± 5.8) and 8 of 18 samples were significantly more toxic than controls (reference 4 in Appendix A).

Another area that was tested for toxicity repeatedly was southwestern San Pablo Bay, an area initially considered as a within-estuary reference area. Sediments from this area have been tested in at least six surveys (references 1, 3, 15, 18, 55, and 56 in Appendix A). There is no obvious pattern of increasing or decreasing toxicity over the nearly 5-year period for which there are data (Table 5). No seasonal patterns are obvious. Nor are there obvious differences in results between the two laboratories which have developed the data.

Table 5. Summary of results of amphipod toxicity tests performed with sediments from southwestern San Pablo Bay.

R. abronius Ave. % mortality ± std. dev.	Ratio of toxic samples to total	Reference no. from Appendix A	Investigator	Sampling period
12.3 ± 10.4	0/3	3	E.V.S.	7/85
26.7 ± 24.0	3/3	1	E.V.S.	2/87
9.0, n=1	0/1	15	E.V.S.	5/87
15.0, n=1	-	18	ToxScan	10/89
37.0, n=1	0/1	55	ToxScan	1/90
29.0, n=1	0/1	56	ToxScan	3/90

The average incidences of abnormal development in bivalve embryos exposed to 50 percent dilutions of suspended sediments are summarized in Table 6. In most cases, the data from the tests of 50 percent dilutions were not evaluated with statistical tests to identify significant differences from controls; so, only the average percent abnormalities were evaluated and compared among areas. Whereas the amphipod bioassays indicated that samples from Guadalupe Slough were relatively low in toxicity, the data from the bivalve tests indicated that they were extremely toxic (average of 87.2 ± 20.7% abnormalities). Other areas that this test identified as relatively toxic included the Suisun Slough channel, Mare Island Strait, and both the Alcatraz and Carquinez disposal sites. Areas identified as least toxic included the Port of San Francisco, Treasure Island, and Oakland Outer Harbor.

Table 6. Average percent abnormality (with standard deviations and numbers of samples tested) among bivalve embryos (*M. edulis, C. gigas*) exposed to sediments (50% diluted suspension) from selected areas of San Francisco Bay and area ranks based upon the average abnormalities (from data listed in Appendix A).

Geographic Area	Average Abnormality (%)	Area Ranks
BASINS		
South Bay, southern part	47.2, n = 1	2
San Pablo Bay	19.5 ± 19, n = 4	10
Central Bay	2.7, n = 1	20
PERIPHERAL AREAS		
Guadalupe Slough channel	87.2 ± 20.7, n = 8	1
Suisun Slough channel	42.8 ± 17.4, n = 2	3
Mare Island Strait	39.1 ± 29.7, n = 10	4
Alcatraz disposal site	28.3 ± 24.4, n = 12	5
Carquinez disposal site	28.1 ± 34.9, n = 6	6
Oakland Middle Harbor	22.2 ± 3.8, n = 6	7
Castro Cove	21.3 ± 8.8, n = 3	8
Richmond Harbor	21.0 ± 16.3, n = 13	9
Pacific Refining	17.9 ± 3.5, n = 4	11
Oakland Inner Harbor	16.9 ± 22.7, n = 24	12
Redwood Creek	16.8 ± 21.8, n = 2	13
UNOCAL	16.2 ± 5.7, n = 3	14
Port of San Francisco	14.7 ± 22.6, n = 20	15
Treasure Island	14.5 ± 3.3, n = 5	16
Oakland Outer Harbor	14.3 ± 25.2, n = 14	17
San Pablo disposal site	7.5, n = 1	18
Alameda Naval Base	7.3, n = 1	19

Table 7 summarizes average incidences of abnormal bivalve embryo development (column A) in tests performed with undiluted (100%) suspended sediments along with the ratios of the total numbers of samples tested to the numbers of samples that were significantly toxic (column B). "Toxic" samples were those determined by the individual investigators to be significantly different from their respective controls. The average percent abnormalities were calculated with data derived from only the EPA/ACOE protocols; whereas, the ratios of toxic versus total samples were calculated from use of both the EPA/ACOE and the Puget Sound protocols. No data (ND) were available from the northern part of South Bay based upon results of tests in which the EPA/ACOE protocols were used. Data from the Pacific Refining and UNOCAL docks were not statistically analyzed to determine which samples were different from controls. The areas were ranked based upon the data in both columns.

Table 7. Results of bivalve embryo toxicity tests (*M. edulis* and *C. gigas*) for areas in San Francisco Bay tested with 100 percent (undiluted) suspensions, based upon data listed in Appendix A. (A) Average percent abnormality (with standard deviations and number of samples) and area ranks based upon the average abnormalities. (B) Ratios of numbers of samples identified as significantly more toxic than respective controls to total numbers of samples tested.

Geographic Area	(A) Average percent Abnormality	Area Ranks	(B) Ratio of Toxic Samples vs. Total (%)	Area Ranks
BASINS				
San Pablo Bay	19.1 ± 31.0 (9)	16	9/16 (56%)	15
South Bay, southern part	14.9 ± 30.6 (8)	19	2/9 (22%)	20
Central Bay	2.4 (1)	23	0/3 (0%)	21
South Bay, northern part	ND	ND	2/3 (67%)	11
PERIPHERAL AREAS				
Pt. Molate	100.0 ± 0 (2)	1	2/2 (100%)	1
Suisun Slough channel	98.5 ± 1.1 (2)	2	2/2 (100%)	1
Islais Creek	ND	ND	4/4 (100%)	1
Guadalupe Slough channel	98.0 ± 4.2 (8)	3	8/8 (100%)	1
Redwood Creek	84.4 ± 21.4 (2)	4	2/2 (100%)	1
Mare Island Strait	76.2 ± 28.7 (10)	5	8/10 (80%)	8
Richmond Harbor	63.8 ± 40.9 (13)	6	10/13 (77%)	9
Hunters Point	59.1 ± 36.7 (6)	7	4/6 (67%)	11
Carquinez disposal site	57.8 ± 39.0 (7)	8	2/5 (40%)	18
Port of San Francisco	55.0 ± 43.5 (19)	9	5/7 (71%)	10
Oakland Middle Harbor	43.1 ± 18.3 (6)	10	6/6 (100%)	1
Alcatraz disposal site	35.5 ± 39.3 (30)	11	13/27 (48%)	17
Oakland Inner Harbor	31.9 ± 35.4 (23)	12	15/29(52%)	16
Treasure Island	29.0 ± 17.5 (11)	13	11/11 (100%)	1
Pacific Refining	22.8 ± 3.8 (4)	14	ND	ND
Castro Cove	21.3 ± 10.9 (3)	15	2/3 (67%)	11
Alameda Naval Base	19.0 ± 15.3 (3)	17	2/3 (67%)	11
Oakland Outer Harbor	18.9 ± 29.2 (18)	18	7/18 (39%)	19
UNOCAL	9.5 ± 1.3 (3)	20	ND	ND
San Pablo disposal site	6.9 (1)	21	0/1 (0%)	21
South Bay, southern channels	5.1 ± 5.4 (16)	22	0/14 (0%)	21

ND indicates no data.

A total of 116 (57.4%) of the 202 samples tested with the bivalve embryos were significantly more toxic than the respective controls (Table 7). All of the sediment samples from the Point Molate area, Suisun Slough channel, Guadalupe Slough channel, Redwood Creek, Treasure Island, Oakland Middle Harbor, the northern part of South Bay (off the Alameda Naval Air Station [NAS]), and Mare Island Strait were toxic in these tests. Both samples from the Point Mollate area were significantly different from controls and 100 percent of the embryos were abnormal. Areas with moderate toxicity included Richmond Harbor, Hunters Point, Carquinez disposal site, Alcatraz disposal site, and Oakland Inner Harbor. Port of San Francisco samples that were among the least toxic in the 50 percent dilution tests were intermediate in toxicity in the undiluted tests. Among the least toxic sediments were those collected from the southern channels and the basin of South Bay below the Dumbarton Bridge, near the UNOCAL and Pacific Refining docks, in Oakland Outer Harbor, in San Pablo Bay, and at the Alameda Naval Base.

Data from bivalve larvae tests were available from the lower reach of the Oakland Inner Harbor in many different reports (references 1, 4, 7, 12, 13, 23, 24, 25, 26, and 42 in Appendix A). These data are summarized in Table 8 for each survey. In four of these surveys average abnormality ranged from 10.5 to 18.3 percent, but in two others they ranged from 64.5 to 100 percent. Unusual colorations of the sediments (suggestive of anti-fouling paints and chromium) were noted in those that caused 100 percent abnormality. Otherwise, all these surveys cited the same methodological protocols, all tested sediments collected in composited cores, and all were collected in a relatively small area. However, the samples were taken during different seasons and from different parts of the lower reach of the Oakland Inner Harbor. Relatively high toxicity was reported by more than one laboratory and in three different surveys conducted 13 months apart. The variability in the toxicity data may reflect the patchiness and heterogeneity in the concentrations of chemicals within regions of the estuary as noted in the preceeding chapter.

Table 8. Summary of results of bivalve larvae tests performed with sediments from the Oakland Inner Harbor.

Bivalve larvae average % abnormality ± standard deviation	Ratio of toxic samples to total	Reference no. from Appendix A	Investigator	Sampling period
10.5 ± 8.3	1/3	7	ToxScan	12/86
24.3 ± 3.2	3/3	1	E.V.S.	2/87
100 ± 0.0	2/2	12	E.V.S	1/88
64.5 ± 41.6	3/5	4	Battelle	3/88
18.3 ± 2.5	2/2	13	E.V.S	11/88
13.1 ± 6.2	2/6	23-26	M.E.C.	8-9/89
14.0 ± 3.5	1/4	42	E.V.S	1/90

Another region in the estuary for which there are bivalve larvae toxicity data from repeated surveys is southwestern San Pablo Bay (Table 9). The average percent abnormalities in the embryos appeared to be somewhat different in the tests performed by the two laboratories. Also, during each of the surveys, the sample sizes were relatively small for this region.

Table 9. Summary of results of bivalve larvae tests performed with sediments from southwestern San Pablo Bay.

Bivalve larvae Ave. % abnormality ± std. dev.	Ratio of toxic samples to total	Reference no. from Appendix A	Investigator	Sampling period
21.1 ± 4.0	0/3	3	E.V.S.	7/85
9.8 ± 3.8	3/3	1	E.V.S.	2/87
13.9, n = 1	1/1	15	E.V.S.	5/87
3.8, n = 1	0/1	18	ToxScan	10/89
7.2, n = 1	0/1	55	ToxScan	1/90
1.8, n = 1	0/1	56	ToxScan	3/90

Data from inner Richmond Harbor were available from four surveys (Table 10), all performed by the same laboratory using the same protocols (references 11, 14, 29, and 30 in Appendix A) and all performed during winter months. The degree of toxicity as determined by percent abnormal development was highly variable during each of the three surveys in which multiple samples were tested. A range of 2.2 to 100% abnormal development was reported. In each survey, at least some of the samples were highly toxic (exceeding 75% abnormality).

Table 10. Summary of results of bivalve larvae tests performed with sediments from Inner Richmond Harbor.

Bivalve larvae Ave. % abnormality ± std. dev. (min. - max.)	Ratio of toxic samples to total	Reference no. from Appendix A	Investigator	Sampling period
62.5 ± 53.7 (24 - 100)	2/2	11	E.V.S.	1/88
27.7 ± 41.5 (2.2-75.6)	1/3	14	E.V.S.	11/88
75.6, n = 1	1/1	29	E.V.S.	2/89
79.3 ± 41.1 (17.7-100)	3/4	30	E.V.S.	12/89

The data from amphipod and bivalve larvae tests were examined to determine which areas in the estuary had a relatively high incidence of very toxic samples (Table 11). The criteria of 50 percent mortality and 50 percent abnormality or greater in the amphipod tests and bivalve larvae tests were used as arbitrary standards. The ratios of the numbers of samples that equalled or exceeded these criteria to the numbers of samples that were tested were determined for selected regions and listed in Table 11. The data from the bivalve larvae tests considered in this approach included only those from the use of the EPA/ACOE methods. Eight out of fourteen samples tested from the central part of South Bay were relatively highly toxic to amphipods (i.e., 50% mortality or greater). In Guadalupe Slough, seven of eight and eight of eight samples were highly toxic to bivalve larvae in the two types of tests. Other areas with relatively high incidences of highly toxic samples included Hunters Point, Richmond Harbor, Mare Island Strait, Suisun Slough channel, and Port of San Francisco. Areas with very low or no incidences of very toxic samples included Central Bay, the northern and southern parts of South Bay, San Pablo Bay, Alameda Naval Base, South Bay channels, and the Pacific Refining and UNOCAL docks.

The data in Table 11 indicate that there was relatively good correspondence in some areas among the three types of tests as regards the proportions of samples that were very toxic, but in other areas there was poor correspondence. For example, small proportions of the samples tested with the three methods were highly toxic in San Pablo Bay, Central Bay, South Bay (southern part), Alameda Naval Base, and South Bay channels. Tests with amphipods and bivalve larvae indicated that small to moderate proportions of samples from Oakland Inner Harbor, Oakland Outer Harbor, Hunters Point, and Islais Creek were relatively highly toxic. On the other hand, the data from Guadalupe Slough sediments tested with amphipods suggested that the sediments were not very toxic, whereas those data from the bivalve tests suggest that the sediments there were extremely toxic. Relatively poor agreement between the amphipod and bivalve larvae tests also occurred in Castro Cove, Richmond Harbor, and Treasure Island.

Table 11. Ratios of total sediment samples tested in selected regions of San Francisco Bay with each of three tests versus the number of samples that equalled or exceeded 50 percent mortalities among *R. abronius* or 50 percent abnormalities among bivalve larvae (*M. edulis, C. gigas*) based upon the data listed in Appendix A.

Geographic Area	Amphipod Mortality (≥50%)	Bivalve Abnormality (50% dilution) (≥50%)	Bivalve Abnormality (No dilution) (≥50%)
		Ratios	
San Pablo Bay	2/17	0/4	1/13
Central Bay	0/3	0/1	0/1
South Bay, northern part	1/9	-	-
South Bay, central part	8/14	-	-
South Bay, southern part	2/13	0/1	1/8
Alcatraz disposal site	0/2	2/12	10/30
Carquinez disposal site	-	1/6	3/7
San Pablo disposal site	-	0/1	0/1
Suisun Slough channel	-	1/2	2/2
Mare Island Strait	-	2/10	7/10
UNOCAL docks	-	0/3	0/3
Pacific Refining	-	0/3	0/3
Castro Cove	2/3	0/3	0/3
Richmond Harbor	0/2	1/13	8/13
Point Mollate	-	0/2	2/2
Treasure Island	3/6	0/5	1/11
Oakland Outer Harbor	2/2	1/14	2/18
Oakland Middle Harbor	-	0/6	3/6
Oakland Inner Harbor	5/24	2/23	5/23
Alameda Naval Base	0/2	0/1	0/3
Port of San Francisco	-	1/19	9/19
Islais Creek	1/3	0/1	1/1
Hunters Point	2/8	-	4/6
Redwood Creek	-	0/2	2/2
South Bay channels	1/9	-	0/16
Guadalupe Slough	0/4	7/8	8/8

One additional approach was used to evaluate the toxicity data in an attempt to identify where extremely toxic sediments had been collected. In this approach, it was assumed that samples that were significantly different from controls and caused 75 percent or more mortality in amphipods or 75 percent or more abnormal development in bivalve larvae were extremely toxic. The locations of the sampling sites in which either 75 percent of more of the amphipods (*R. abronius* and *E. estuarius*) died or 75 percent or more of the bivalve larvae (*M. edulis* and *C. gigas*) were abnormal are shown in Figure 12. Each star in Figure 12 represents the sampling location of an individual sample that was extremely toxic, using the arbitrary 75 percent criteria mentioned above. The data from the bivalve larvae tests considered in this approach included those from both the EPA/ACOE and Puget Sound protocols, therefore more data were considered than in Table 11.

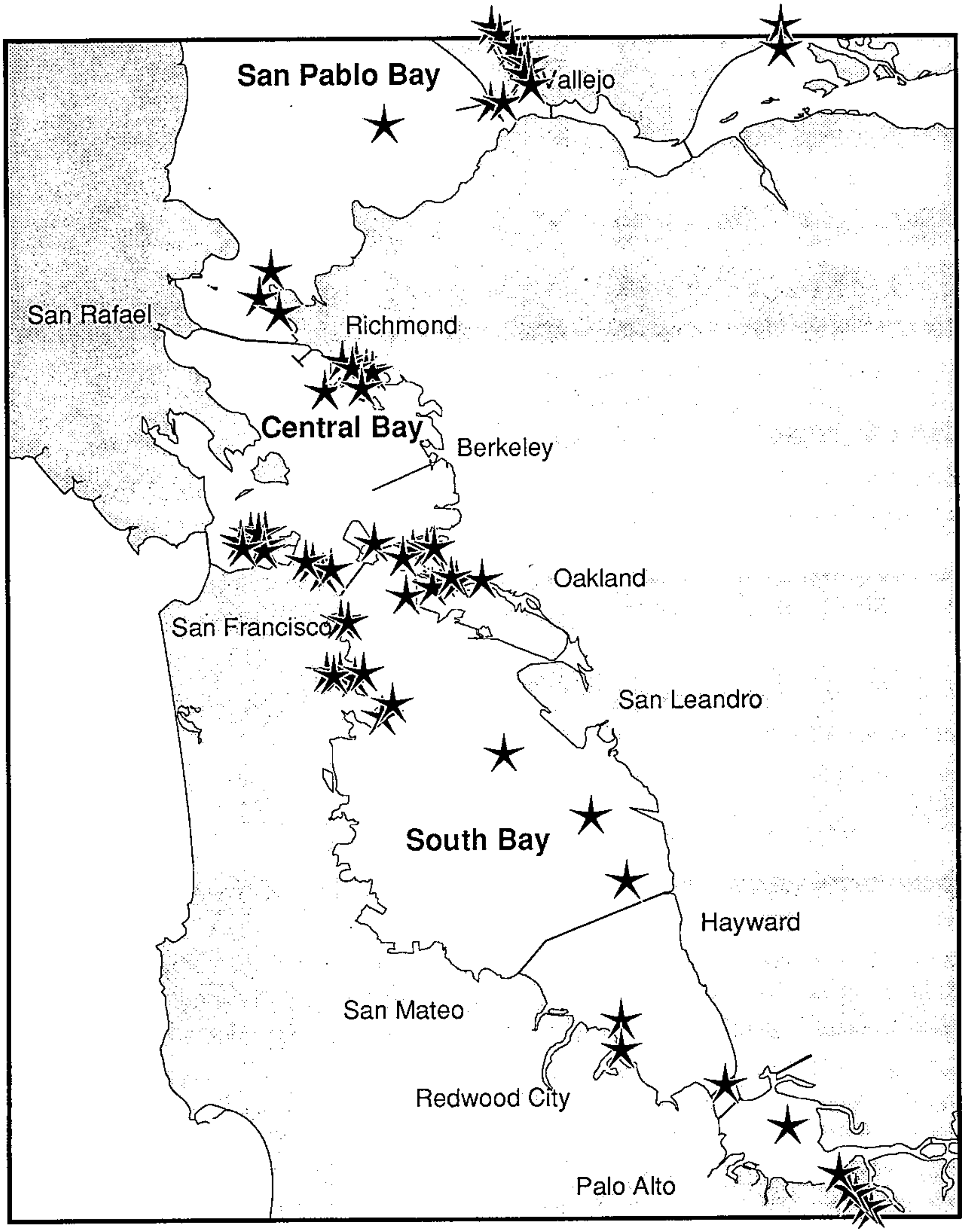

Figure 12. Sites in which sediments caused 75 percent or greater mortality in amphipods or abnormal development in bivalve larvae based upon data listed in Appendix A.

The locations indicated in Figure 12 as extremely toxic can be compared to all of the locations shown in Figure 11 for which there are data. Extremely toxic samples were scattered throughout the estuary, but clusters of stations were apparent in the vicinity of Oakland, San Francisco, Vallejo, Alcatraz, Richmond, and the southern channels of South Bay.

The sites that were extremely toxic (sediment samples caused 75% or more mortality in amphipods or 75% or more abnormality in bivalve larvae) were located:

- along the Port of San Francisco shoreline (9 samples);
- at the Alcatraz disposal site (8 samples); in Guadalupe Slough (8 samples);
- in inner Richmond Harbor (7 samples);
- in Mare Island Strait (7 samples);
- in Oakland Inner Harbor (5 samples);
- in Oakland Outer Harbor (4 samples);
- in Islais Creek Channel (4 samples);
- in southern South Bay near or below the Dumbarton Bridge (3 samples);
- at the Carquinez disposal site (2 samples); off Point Mollate (2 samples);
- in Suisun Slough channel (2 samples); off Hunters Point (2 samples);
- in South Bay off San Leandro (2 samples); in Redwood Creek (2 samples);
- in Richmond Outer Harbor (1 sample);
- in Pinole shoal channel (1 sample);
- off Treasure Island (1 sample);
- off the Alameda Naval Air Station (1 sample);
- and in outer Castro Cove (1 sample).

At least one sample from each of these sites elicited a very high toxicological response in one or the other of the two bioassays or both. Most of these sites were located in peripheral areas, but some were located in the basins.

Relationships Between Sediment Contamination and Toxicity

The San Francisco estuary has received many kinds of organic compounds and trace elements, any and all of which have a potential for being toxic to resident organisms. These toxicants occur in the estuary in different proportions and mixtures. As estimated in the previous chapter, some of these chemicals occur in the estuary in concentrations that could cause toxicity. It is of interest to estimate which, if any, of the physical-chemical parameters of sediments were most closely associated with toxicity. In this section, matching, paired sediment chemistry and toxicity data were compared using two methods applied to the same data. The correlations between chemical and physical variables and toxicity were determined. Also, the chemicals that were most elevated in concentration in toxic samples compared to nontoxic samples were identified.

Initial evaluations of matching sediment chemistry and bioassay data from San Francisco Bay have been performed to determine Apparent Effects Thresholds (AETs), the concentrations above which significantly toxic effects were always observed (Becker *et al.*, 1990; Long and Morgan, 1990). Also the mean chemical concentrations co-occurring with significantly toxic sediments have been compared to the mean concentrations in nontoxic sediments (Long and Morgan, 1990).

In both the AET and co-occurrence approaches to the evaluation of matching field-collected data, it is assumed that some agent(s) in the sediments caused the toxic response elicited in the bioassays. Those agent(s) may have included the chemicals that were quantified in the chemical analyses, but, also may have included chemicals that were not quantified or other natural physical-chemical properties of the sediments.

In Puget Sound, AET concentrations (Barrick *et al.*, 1988) have been used to establish marine sediment quality standards for Washington State. Generally, there was a good degree of correspondence, or concordance, between the toxicity data and the matching chemical data. DeWitt *et al.* (1988) calculated the mean concentrations of six trace metals, tPCBs, and tPAHs in Puget Sound that co-occurred with significant toxicity to *R. abronius* and compared those concentrations with those in sediments that were not toxic to the amphipods. The samples analyzed by DeWitt *et al.* (1988) that were highly toxic had mean chemical concentrations 2.0 to 44.5 times higher than those that were not toxic. The average of the ratios between the chemical concentrations in toxic samples and the nontoxic samples was 12.2. That is, on average, the toxic samples were 12.2 times more highly contaminated than nontoxic samples based upon the quantification of eight analytes. In Commencement Bay samples that were analyzed by Tetra Tech (1985), the average of the ratios between 25 chemical concentrations in samples toxic to *R. abronius* versus those not toxic to *R. abronius* was 14.8 (from Long and Morgan, 1990). The ratios ranged from 0.6 to 102. In analyses of sediments from southern California (Anderson *et al.*, 1988), the average of the ratios of 27 chemical concentrations in samples toxic to *Grandidierella japonica* versus those not toxic to this amphipod was 2.95 (from Long and Morgan, 1990). The ratios ranged from 0.6 to 9.6.

Correlation Analyses. Matching chemical and toxicity data were available from some of the reports listed in Appendix A. Data from chemical analyses and the amphipod tests with *R. abronius* were extracted from Long and Buchman (1989); U.S. Navy (1987); Chapman *et al.* (1987); and Word *et al.* (1988). Data from chemical analyses and bivalve larvae tests were extracted from the same four references plus references 13, 14, and 42 in Appendix A. These matching data from the different reports were merged and correlations between toxicity test results and physical-chemical parameters were determined. The amount of data available differed between the two toxicity tests and among the physical-chemical variables (Table 12).

Generally, chemicals often associated with anthropogenic sources were relatively highly correlated with toxicity to bivalve larvae. The highest positive correlations were between percent abnormal development in bivalve larvae and a number of PAHs and classes of PAHs. Low and high molecular weight PAHs were most highly correlated with these toxicity test results. Many of the correlations were highly significant. Bivalve larvae abnormalities also were relatively highly correlated with total tin, tributyl tin, Pb, Cu, Ag, and p,p'-DDT, but not with percent fine-grained sediments, again suggesting that these chemicals were of anthropogenic origins.

The correlation coefficients for the amphipod mortality test results generally were lower than the corresponding coefficients for the bivalve larvae tests. The variables that correlated most highly with amphipod mortality were concentrations of total organic carbon (TOC) and benzo(e)pyrene. Similar to the bivalve larvae tests, amphipod mortality was significantly correlated with several PAHs, Cd, Pb, and p,p'-DDE; chemicals often associated with anthropogenic inputs.

Based upon relatively small sample sizes, Spies (1989a) and Davis *et al.* (1990) concluded that there were no apparent correlations between toxicity and toxicants in San Francisco Bay sediments. They suggested that there were better correlations between toxicity and both TOC content and grain size. Data from 15 samples reported by Long and Buchman (1989) also indicated a positive relationship between toxicity to both mussel larvae and amphipods and TOC content, but not with percent fine-grained sediments. The correlations with the concentrations of Hg and a few groups of organic compounds also were positive, but weaker than those for TOC content. In the present evaluation performed with larger data sets, the correlations between toxicity and the concentrations of a number of anthropogenic toxicants were relatively strong and very significant, the correlation with percent fine-grained sediments was not significant, and the correlation with TOC content was significant, but weaker, than that for many toxicants. The correlations between amphipod mortality and both TOC content and benzo(e)pyrene concentrations were significant and relatively strong, whereas the correlation with fine-grained sediments was weaker and significant at P = 0.07.

Table 12 Correlation (R^2) coefficients for matching sediment toxicity and chemistry data from San Francisco Bay. Correlations that were statistically significant (P=0.10) are accompanied with asterisks and corresponding P values.

	Bivalve Larvae Percent Abnormal Development		Amphipod Percent Mortality	
Chemical or physical variable	correlation coefficient (P)	Sample Size	correlation coefficient (P)	Sample Size
p,p-DDE	+0.007	36	+0.120* (0.10)	24
p,p-DDT	+0.122* (0.03)	37	+0.055	24
naphthalene	+0.007	37	+0.036	24
2-methyl naphthalene	+0.354* (0.002)	24	+0.052	24
1-methyl naphthalene	+0.165* (0.05)	24	+0.013	24
biphenyl	+0.421* (0.006)	24	+0.140* (0.07)	24
2,6-methyl naphthalene	+0.359* (0.002)	24	+0.160* (0.05)	24
fluorene	+0.219* (0.002)	39	+0.026	43
phenanthrene	+0.295* (0.0003)	39	+0.060	42
1-methyl phenanthrene	+0.528* (0.0001)	23	+0.169* (0.05)	23
fluoranthene	+0.254* (0.001)	40	+0.077* (0.08)	42
chrysene	+0.348* (0.0001)	40	+0.066* (0.10)	42
benzo(e)pyrene	+0.348* (0.0001)	24	24+0.201* (0.03)	24
low molecular weight PAH	+0.556* (0.0001)	24	+0.140* (0.07)	24
high molecular weight PAH	+0.574* (0.0001)	24	+0.135* (0.08)	24
sum of 16 to 18 PAH	+0.208* (0.003)	40	+0.050	42
total PCB	+0.078* (0.08)	40	+0.018	42
silver	+0.228* (0.002)	40	+0.055	42
arsenic	+0.125* (0.01)	50	-0.031	53
cadmium	+0.116* (0.03)	40	+0.101* (0.04)	43
chromium	+0.039	51	-0.009	52
copper	+0.165* (0.003)	51	+0.026	53
lead	+0.136* (0.01)	51	+0.153* (0.004)	53
mercury	+0.003	51	+0.039	53
nickel	+0.144* (0.006)	51	+0.009	53
selenium	+0.122* (0.03)	40	+0.019	42
tin	+0.434* (0.0005)	24	+0.015	24
zinc	+0.160* (0.004)	51	+0.026	53
tributyl tin	+0.289* (0.03)	16	-0.041	18
percent silt+clay	+0.040	40	+0.071* (0.07)42	42
percent total organic carbon	+0.191* (0.001)	51	+0.291* (0.0002)	42

Co-occurrence Analyses. The same data used in the correlation analyses also were used to determine the average chemical concentrations associated with toxic sediments. A summary of the chemical concentrations co-occurring with significantly toxic and nontoxic sediment samples from San Francisco Bay tested with *R. abronius* is presented in Table 13. A total of 53 samples were analyzed for toxicity; 53 or fewer of these samples were analyzed for each of the chemicals listed in the table. "Significantly toxic" sediments were those identified by the individual analysts as significantly different (more toxic) than the respective controls. Co-occurrence analyses were not performed for some chemicals (*i.e.*, many aromatic hydrocarbons) evaluated with correlation analyses due to small sample sizes among nontoxic samples. The ratios between the mean chemical concentrations in toxic samples versus nontoxic samples are listed along with the AET values derived by Becker *et al.* (1990) for northern California or by Long and Morgan (1990) for San Francisco Bay.

As compared to Puget Sound, Commencement Bay, and southern California, the ratios between the chemical concentrations in toxic samples versus nontoxic samples from San Francisco Bay were very small; the average of the ratios was 1.3 (Table 13). The average concentrations of some chemicals (*i.e.*, those with ratios of less than 1.0) were higher in the nontoxic samples than in the significantly toxic samples. These chemicals (arsenic, chromium, copper, selenium, acenaphthene, and fluorene) were weakly or not significantly correlated with the toxicity results (Table 12). With a ratio of 8.0 between concentrations in toxic versus nontoxic samples, the concentration of p,p'-DDT showed the highest degree of elevation in the toxic samples. The mean concentration of p,p'-DDT nearly equalled the AET and the concentrations in some samples exceeded the AET. However, the concentrations of p,p-DDT were not significantly correlated with toxicity to *R. abronius* (Table 12). The standard deviations often equalled or exceeded the mean chemical concentrations, indicating a large degree of variability. In addition, the AET values were often much higher than the mean chemical concentrations co-occurring with toxic samples, indicating that there were some toxic samples with relatively low chemical concentrations and that the mean concentrations never equalled the AET for those chemicals.

Table 13 also lists the mean percent of fine-grained sediments (silt + clay) and total organic carbon (TOC) content associated with toxic and nontoxic samples. The average percent fines in toxic samples was 87.1 ± 12.4 percent (range of 47.2 to 97.8%), compared to the average of 76.2 ± 19.6 percent (range of 23.3 to 94.1%) in nontoxic sediments. The ratio between the two means was 1.1, slightly lower than the ratio of 1.3 between the chemical concentrations in toxic and nontoxic samples. The ratio between the average TOC content in toxic samples versus nontoxic samples was 1.1. The correlation between amphipod mortality and percent fines was relatively small (but significant).

Table 13. **Mean chemical concentrations (and standard deviations) in San Francisco Bay sediments determined to be either toxic or not toxic to *R. abronius* (from Long and Morgan, 1990), ratios between these concentrations, and AET values derived by Becker *et al.* (1990) for northern California.**

Chemical Analyte	Significantly Toxic (42.9±19.2% mortality,n = 34)	Not Toxic (18.4±6.8% mortality, n = 19)	Ratio of Means	AET Value
Trace Metals (ppm)				
Arsenic	15 ± 14, n = 34	30 ± 22, n = 19	0.5	>72
Cadmium	0.6 ± 0.4, n = 24	0.6 ± 0.3, n = 19	1.0	1.7
Chromium	155 ± 102, n = 33	203 ± 97, n = 19	0.8	>240
Copper	70 ± 47, n = 34	75 ± 43, n = 19	0.9	98
Lead	58 ± 61, n = 34	54 ± 36, n = 19	1.1	120
Mercury	0.7 ± 0.8, n = 34	0.6 ± 0.4, n = 19	1.2	1.2
Selenium	0.6 ± 0.3, n = 23	0.9 ± 0.5, n = 19	0.7	0.2
Silver	1.2 ± 1.7, n = 23	1.4 ± 1.9, n = 19	0.9	>8.6
Zinc	158 ± 87, n = 34	177 ± 96, n = 19	0.9	230
Organic Compounds (ppb)				
Acenaphthene	5.9 ± 17, n = 15	12 ± 17, n = 9	0.5	56
Anthracene	120 ± 277, n = 23	120 ± 269, n = 19	1.0	1100
Benzo(a)pyrene	429 ± 382, n = 23	423 ± 465, n = 19	1.0	>1300
Benzo(e)pyrene	268 ± 276, n = 15	157 ± 206, n = 9	1.7	690
Chrysene	423 ± 512, n = 23	405 ± 571, n = 19	1.0	2100
Fluoranthene	583 ± 789, n = 23	572 ± 880, n = 19	1.0	>3700
Fluorene	29 ± 48, n = 24	43 ± 51, n = 19	0.7	210
Naphthalene	53 ± 38, n = 15	65 ± 54, n = 9	0.8	>160
Phenanthrene	220 ± 163, n = 23	199 ± 205, n = 19	1.1	510
Pyrene	896 ± 870, n = 23	743 ±902, n = 19	1.2	2600
Low PAH	557 ± 767, n = 15	532 ± 844, n = 9	1.0	2100
High PAH	2482 ± 3201, n = 15	2086 ± 3696, n = 9	1.2	>11,000
Total PAH	3832 ± 3927, n = 23	3570 ± 4499, n = 19	1.1	>15,000*
Total PCB	146 ± 218, n = 23	101 ± 153, n = 19	1.4	260
p,p'-DDT	8 ± 18, n = 15	1 ±3, n = 9	8.0	9.6
Dieldrin	7.6 ± 7.5, n = 13	6.2 ± 0.6, n = 2	1.2	6.6
Average of ratios				
San Francisco Bay			1.3	
Puget Sound			12.2	
Commencement Bay			14.8	
Southern California			2.95	
Sum of % silt + clay	87.1 ± 12.4 n = 23	76.2 ± 19.6 n = 19	1.1	na
TOC (%)	1.66 ±0.6, n = 23	1.45 ± 0.6, n = 19	1.1	na

*AET value for total PAH from Long and Morgan (1990).

Ratios similar to those presented above for the amphipod bioassay data are listed in Table 14 for the bivalve larvae bioassays performed in San Francisco Bay. The average chemical concentrations in 38 samples that were determined to be significantly toxic were compared with the concentrations in 13 nontoxic samples; and, the ratios of the two averages were determined. The data were the same as those used in the correlation analyses. Co-occurrence analyses were not performed for some chemicals (*i.e.*, many aromatic hydrocarbons) evaluated with correlation analyses due to the small sample sizes among nontoxic samples. The AET values calculated by Becker *et al.* (1990), based upon a combined data set for all of California, are presented in Table 14.

The analogous ratios for bivalve larvae test results (Table 14) were much higher than for the amphipod test results (Table 13), as indicated (Table 12) in the higher correlation coefficients. That is, based upon both the correlation analyses and the co-occurrence analyses there appears to be a stronger relationship between toxicity and toxicant concentrations for the bivalve larvae tests than for the amphipod tests.

The chemical concentrations in toxic samples, on average, were 1.8 times higher than the concentrations in samples that were not toxic. The ratios ranged from 0.4 to 4.7 for the 32 analytes. The chemicals most elevated in toxic samples relative to nontoxic samples were tributyltin, p,p'-DDT, anthracene, benz(a)anthracene, chrysene, dibenzo(a,h) anthracene, and fluorene. The mean concentrations of p,p'-DDT and dibenzo(a,h) anthracene approached or equalled the respective AET values. Generally, those chemicals that were most highly correlated with toxicity test results were most highly elevated in average concentrations in the toxic samples.

The average of the ratios between 25 chemical concentrations in Commencement Bay samples analyzed by Tetra Tech (1985) that were toxic to bivalve larvae versus those that were not toxic (listed by Long and Morgan, 1990) was 6.8. The analogous average of the ratios was much smaller, 1.8, in San Francisco Bay. The ratios of the average percent fine-grained sediments and TOC in toxic versus nontoxic samples in San Francisco Bay were 1.2 and 1.1, respectively. The average concentrations of chromium, dieldrin, and naphthalene were higher in nontoxic samples than in samples that were toxic.

Table 14. Mean chemical concentrations (and standard deviations) in San Francisco Bay sediments determined to be either toxic or not toxic to bivalve larvae (from Long and Morgan, 1990), ratios between these concentrations, and AET values derived by Becker et al. (1990) for all of California.

Chemical Analyte	Significantly Toxic (57.3±26.6% abnormality, n = 38)	Not Toxic (14.8±11.9% abnormality, n = 13)	Ratio of Means	AET Value
Trace Metals (ppm dw)				
Arsenic	21.8 ± 21.4, n = 37	14.2 ± 12.6, n = 13	1.5	70
Cadmium	0.6 ± 0.4, n = 28	0.5 ± 0.3, n = 12	1.2	0.57
Chromium	139.1 ± 90.7, n = 38	167.2 ± 56.6, n = 13	0.8	>240
Copper	67 ± 46, n = 38	61 ± 30, n = 13	1.1	66
Lead	56.4 ± 60.3, n = 38	49 ± 30, n = 13	1.2	71
Mercury	0.8 ± 1.0, n = 38	1.1 ± 2.0, n = 13	0.7	0.51
Nickel	98.4 ± 33.5, n = 38	92 ± 28.6, n = 13	1.1	>170
Selenium	0.7 ± 0.5, n = 28	0.4 ± 0.4, n = 12	1.8	na
Silver	1.6 ± 2.1, n = 28	0.6 ± 0.3, n = 12	2.7	2.3
Zinc	153 ± 86, n = 38	152 ± 63, n = 13	1.0	150
Tributyltin				
(ppm dry wt.)	0.137 ± 0.220, n = 7	0.029 ± 0.031, n = 9	4.7	na
Organic Compounds (ppb dw)				
p,p'-DDT	7.9 ± 22.4, n = 26	1.7 ± 3.1, n = 11	4.6	9.6
p,p'-DDE	3.2 ± 5.9, n = 25	3.1 ± 2.9, n = 11	1.0	2.3
Dieldrin	6.0 ± 7.2, n = 17	15.7 ± 29.6, n = 10	0.4	6.6
Acenaphthene	9.2 ± 16.9, n = 25	6.8 ±9.8, n = 11	1.4	16
Anthracene	167 ± 324, n = 28	50 ± 33, n = 12	3.3	60
Benz(a)anthracene	55 ±76, n = 28	22 ± 20, n = 12	2.5	150
Benzo(a)pyrene	453 ± 446, n = 28	302 ± 288, n = 12	1.5	430
Chrysene	471 ± 627, n = 28	163 ± 195, n = 12	2.9	190
Dibenzo(a,h)anth.	63 ± 80, n = 28	21 ± 22, n = 12	3.0	63
Fluoranthene	638 ± 971, n = 28	296 ± 349, n = 12	2.2	39
Fluorene	31 ± 60, n = 28	12.5 ± 16, n = 11	2.5	19
Naphthalene	45 ± 41, n = 25	69 ± 142, n = 12	0.7	>160
Phenanthrene	221 ± 197, n = 28	125 ± 130, n = 11	1.8	170
Pyrene	697 ± 935, n = 28	471 ± 709, n = 12	1.5	490
Total PAH	3783 ± 4619, n = 28	2752 ± 2765, n = 12	1.4	870*
Total PCB	113 ± 162, n = 28	128 ± 212, n = 12	0.9	88
Average of Ratios				
San Francisco Bay			1.8	
Commencement Bay			6.8	
Percent silt & clay	87.4 ± 13.4, n = 28	76.0 ± 23.4, n = 12	1.2	
TOC	1.29 ± 0.76, n = 38	1.13 ± 0.41, n = 13	1.1	

*AETs value for total PAH from Long and Morgan (1990).

SUMMARY

Data available from 60 studies were merged and reviewed to determine spatial extent of sediment toxicity in the estuary and to determine the relationships, if any, between toxicity and chemical contamination in sediments. Several procedures were used to evaluate the data.

The determination and delineation of the extent of sediment toxicity based upon the historical data was hindered by a number of factors. Many areas that could be toxic have not been tested for toxicity or have been undersampled, so it was difficult to identify the spatial extent of toxicity. For example, much of the basin areas of the estuary have not been tested. However, some data were available for most regions of the estuary. The data available from these 60 studies were generated during several years by different laboratories. They were not collected at a single time by one laboratory. Different sediment sampling protocols were used in some of the 60 different studies. Some subtle differences in the execution of ostensibly similar testing methods could have occurred among laboratories and between years. However, in most cases, there did not appear to be any systematic differences in results among laboratories. Differences in the viability and performance of batches of test organisms could have occurred among the 60 studies. Because of these factors, the generalizations in the patterns described below in toxicity must be viewed with caution until additional testing can verify the conclusions.

Toxicity occurred more frequently in peripheral areas than in the basins, especially as determined in the undiluted bivalve embryo bioassays. In the bivalve embryo tests, a total of 42 percent (13 of 30) of the samples from the basins were significantly toxic, compared to 60 percent (103 of 169) in sediments from peripheral areas. In the amphipod tests 39 percent (13 of 33) in the basins and 55 percent (43 of 78) in the peripheral areas were significantly toxic.

In some areas, considerable amounts of data have been generated. However, they have been collected in different surveys performed in different years and seasons. Data from some areas were highly variable, even in relatively small areas. This patchiness could have been a result of very high heterogeneity in chemical concentrations within these areas. Comparisons of ambient chemical data and concentrations previously associated with toxicity indicated that there often was a very high degree of variability in concentrations within relatively small areas. Therefore, the potential for toxic effects would be expected to vary considerably within these areas. The available evidence does not suggest that the variability in toxicity data within these areas was a function of the seasons or the laboratories performing the analyses.

Based upon the cumulative evidence of (1) the average percent mortality in the amphipod tests, (2) the average percent abnormality in the bivalve embryo tests, (3) the percent of the samples that were significantly more toxic to amphipods than controls, and (4) the percent of the samples that were significantly more toxic to bivalve embryos than controls; the areas tested thus far with the highest toxicity were (more or less in order of descending toxicity):

- Point Molate, Suisun Slough channel,
- the central portion of South Bay (between the San Mateo and Dumbarton bridges),
- Islais Creek,
- Mare Island Strait,
- Oakland Middle Harbor,
- Redwood Creek,

- vicinity of Hunters Point,
- Guadalupe Slough,
- Castro Cove,
- Richmond Harbor,
- and near the Treasure Island Naval Base.

Sediments from these areas generally caused the highest incidences of abnormal development in bivalve embryos and/or the highest incidences of mortality in amphipods, and had the highest frequencies of toxic samples relative to the numbers of samples that were tested. All but one of these areas (central portion of South Bay) are peripheral areas located either in industrial harbors or industrial channels, and/or are near major industrial or military facilities around the perimeter of the estuary. Also, all but the central portion of South Bay are relatively small areas with readily definable channel boundaries or other limits.

Based upon these cumulative data, the areas tested thus far that were intermediate in toxicity included:

- northern part of South Bay,
- Alcatraz disposal site,
- Carquinez disposal site,
- Oakland Inner Harbor,
- Oakland Outer Harbor,
- vicinity of Alameda Naval Base,
- and the Port of San Francisco.

Again, based upon the cumulative evidence, the areas tested thus far that were among the least toxic included:

- San Pablo Bay near the UNOCAL and Pacific Refining docks,
- southwestern San Pablo Bay,
- Central Bay,
- the southern South Bay channels and sloughs (except Guadalupe Slough),
- and southern South Bay (south of the Dumbarton Bridge).

Average incidences of abnormal development in bivalve embryos and average incidences of mortality in amphipods often were lowest in sediments from these areas and/or the frequencies of significantly toxic samples were lowest there.

Chemical data were available in Long *et al.* (1988) from many of the regions for which there were, also, historical toxicity data collected in later surveys (Table 15). In Table 15, those chemicals are identified in each region that equalled or exceeded the ERM guideline values from Long and Morgan (1990). These exceedances were illustrated in Figures 2 through 10. Data were available for most, but not necessarily all, of the analytes for all of the regions. Also listed in Table 15 are average mortalities in amphipod tests, average abnormalities in bivalve larvae tests, and percents of the samples tested that were significantly more toxic than controls (data from Tables 4 and 7). There were no toxicity data available for some areas for which there were chemical data and vice versa.

Except for Castro Cove, all regions for which chemical data were available had at least one chemical that equalled or exceeded an ERM guideline. Also, all regions for which toxicity data were available had samples that were toxic in one or both tests. Sediments from some regions (*e.g.*, Guadalupe Slough, Central Bay, South Bay) were determined to be toxic in one test, but not in the other test. The region that generally was relatively low in toxicity (San Pablo Bay), nevertheless, had relatively high concentrations of trace metals. Importantly, none of the regions for which there are data available were nontoxic <u>and</u> relatively uncontaminated.

Much of these data are contradictory and few clear spatial patterns in toxicity and concordance between chemical data and toxicity data are apparent. However, several regions appeared to be both relatively highly toxic and highly contaminated.

The maximum and median concentrations of several trace metals exceeded the respective ERM values in sediments collected along the Port of San Francisco shore. In bivalve larvae tests, 70 percent (5 of 7) of the samples from this region were toxic. Islais Creek Waterway had very high concentrations of PAH, PCB, and four trace metals in the sediments. Sediments from that region were very toxic to bivalve larvae and amphipods. Hunters Point sediments had high concentrations of silver and they were toxic to amphipods. Three trace metals were elevated in concentration in Oakland Outer Harbor and two samples from this region tested with amphipods were very toxic. Sediments from Richmond Harbor had high concentrations of DDT and three trace metals and 77 percent (10 of 13) samples were toxic to bivalve larvae. Sediments from Mare Island Strait had high concentrations of three trace metals and 80 percent of the samples tested with bivalve larvae were toxic.

Since the concentrations of many chemicals generally were relatively high in some peripheral areas (Figures 2 through 10) where sediments often were toxic (Tables 3, 4, 6, and 7) it was of interest to determine which individual chemicals or chemical groups were most highly associated with the toxicity. Data analyses were performed to determine the correlations between toxicity and chemical concentrations and to determine the average concentrations in both toxic samples and nontoxic samples. Based upon these analyses, there is evidence that some anthropogenic toxicants, particularly some of the PAHs, were associated with the toxicity in sediments. The concentrations of many PAHs and classes of PAHs were highly correlated with toxicity to bivalve larvae, and, to a lesser extent, to amphipods. The concentrations of the PAHs were highest in peripheral areas, such as Islais Creek, India Basin, and China Basin (Figure 9), that often were toxic to bivalve larvae and/or amphipods (Tables 4 and 7). Other chemicals usually associated with anthropogenic sources, namely Pb, Ag, Sn, tributyl tin, and DDT, also were correlated with toxicity and often highly concentrated in certain peripheral areas that frequently were toxic (Table 15). The average concentrations of DDT were highly elevated in samples that were significantly toxic to bivalve larvae and amphipods

The correlations between most of the other physical-chemical parameters and toxicity were relatively low, although many were statistically significant. An exception, percent TOC content, was relatively highly correlated with toxicity to amphipods. The ratios of the average concentrations of chemical contaminants in sediments that were significantly toxic to those that were not toxic were much lower in San Francisco Bay than the analogous ratios for Puget Sound, Commencement Bay, and southern California.

Table 15. Regional comparison of exceedances of effects-based chemical guidelines (from Figures 2 through 10) with summarized historical sediment toxicity data (from Tables 4 and 7).

Region	Median[a] concentration ≥ ERM value	Maximum concentration ≥ ERM value	Average amphipod mortality	Percent of samples toxic to amphipods	Average percent abnormalities among bivalve larvae	Percent of samples toxic to bivalve larvae
Port of San Francisco	Ag, Cr, Pb	Ag, Cr, Pb, Hg	ND	ND	55%	71%
Islais Creek	Ag, PAH, PCB	Ag, Cr, Pb, Hg	52%	67%	ND	100%
Hunters Point		Ag	37%	100%	59%	67%
Guadalupe Slough		Hg	21%	0%	98%	100%
Redwood City Harbor		Cr, Pb	ND	ND	84%	100%
Oakland Inner Harbor		Pb, Hg	36%	56%	32%	52%
Oakland Middle Harbor	ND	ND	ND	ND	43%	100%
Oakland Outer Harbor		Ag, Cr, Pb	75%	100%	19%	39%

Table 15. Continued

Treasure Island	ND	ND	48%	100%	29%	100%
Richmond Harbor	DDT	Cu, Pb, Hg	27%	100%	64%	77%
Castro Cove			60%	100%	21%	67%
Point Molate	ND	ND	ND	ND	100%	100%
Alameda NAS		Pb	33%	100%	19%	67%
Mare Island Strait		Ag, Cr, Pb	ND	ND	76%	80%
South Bay[b]		Ag, Cd, Cr, Hg	25/55/32%	0/ND/50%	ND/ND/15%	67/ND/22%
San Pablo Bay	Cr	Cr, Pb, Hg	23%	27%	19%	56%
Central Bay		Cr, Pb, Hg	33%	100%	2%	0%
Alcatraz Disposal Site	ND	ND	11%	0%	35%	48%

ND indicates no data.

[a] Mean concentrations were used for organic compounds.

[b] Regional data for northern/central/southern parts of South Bay, respectively.

Although the correlations between toxicity and the concentrations of some of the chemicals look promising, they do not constitute empirical evidence of cause/effect relationships. Further laboratory work is needed to establish those relationships. However, the present evaluation does indicate that there are positive associations between toxicity and some anthropogenic toxicants, not just natural sedimentological factors.

In any evaluation of matching chemical and biological data from field studies, such as that presented here, there are a number of cautionary factors to consider. First, to provide a sufficient sample size to evaluate, the data that were evaluated were merged from many different studies. These studies were conducted in different parts of the estuary. The data may represent conditions in different pollution gradients with different proportions (fingerprints) and absolute concentrations of contaminants. As a result, some samples from one part of the estuary that were toxic may have had high concentrations of some chemicals that occurred in low concentrations elsewhere in other samples that also were toxic. As a consequence of merging the data sets from the different areas, the distinctions between toxic and nontoxic conditions may have been obscured. However, without merging data sets, the sample sizes for any particular area in the estuary would be very small, precluding any meaningful comparisons of the data.

Second, physical and/or chemical factors that have not yet been quantified may contribute to toxicity in the bioassays. Factors such as angularity of sediment grains, asbestos fibers from nearby crysotile deposits, or natural, biogenically derived toxicants may cause or contribute to the toxicity observed in the bioassays. Some evidence suggests that unionized ammonia concentrations are correlated with sediment toxicity (Mike Carlin, San Francisco Bay Regional Water Quality Control Board, personal communication). Third, differences in organic carbon content and chelation by sulfides in the sediments may alter the bioavailability of the toxicants in the sediments sufficiently to influence the results of the toxicity tests. Subtle differences in bioavailability of the potential toxicants may trigger or inhibit positive toxicity test responses. Additional, carefully designed studies may elucidate promising toxicity/toxicant relationships.

CHAPTER 3
SYNOPTIC SURVEY OF SEDIMENT TOXICITY

METHODS

Overall Approach

A battery of tests of sediment toxicity were performed by ToxScan, Inc. (Watsonville, California) as indicators of the potential for biological effects associated with toxicants in the sediments of San Francisco Bay. Existing chemical data (summarized by Long *et al.*, 1988) from analyses of sediments were used to design a sampling plan. The sampling plan was intended to determine spatial patterns and extent in sediment toxicity. A total of 45 sampling sites was sampled once (three samples per site) and tested with a battery of bioassays. Patterns in toxicity were determined using a variety of arithmetical, statistical, and graphical methods. Also, an attempt was made to develop methods for identifying cytogenetic effects in bivalve embryos, similar to the methods used to identify these endpoints in sea urchin embryos (Hose, 1985).

The toxicity tests chosen for the survey were those performed with bivalve embryos, bioluminescent bacteria, and sea urchin embryos. The bivalve embryo test for survival and abnormal morphological development had been shown in a previous study (Long and Buchman, 1989) to have very high sensitivity, high discriminatory power, and low within-sample variability. A variety of cytogenetic endpoints in sea urchin embryos also performed well in the same study. The bioluminescence test had been performed in Puget Sound (Schiewe *et al.*, 1985) and had been used to identify a gradient in toxicity when exposed to organic extracts of sediments.

Sediment Sampling and Handling

The sediment chemistry data evaluated by Long *et al.* (1988) indicated that the highest concentrations of most toxicants were found in many of the peripheral harbors and waterways of the bay, in parts of South Bay, and in the eastern shoals of Central Bay off the cities of Berkeley and Emeryville. Therefore, the sampling effort was focused upon these areas (Figure 13).

Sediments were collected at 45 sites. Sites located in Richmond Harbor, Oakland Outer Harbor, Oakland Inner Harbor, San Leandro Bay, China Basin, Islais Creek Waterway, and Redwood Creek were expected to be the most toxic. Sites located along the Berkeley/Emeryville shore of Central Bay, off the Alameda NAS, along the South San Francisco/San Mateo shore of South Bay, in South Bay below the San Mateo Bridge, and in Guadalupe Slough below the Dumbarton Bridge were expected to be moderately toxic. Sites in north-central South Bay and northwest of Treasure Island were expected to be least toxic, along with a site in southwestern San Pablo Bay that was regarded as a within-system reference site. A site near Raft Island in lower Carr Inlet of Puget Sound, Washington was sampled and tested as the negative sediment control for each batch of samples.

Three separate samples, one at each of the stations, were collected at 30 of the 45 sites. The contents of the three samples were not pooled; rather, they were tested separately. At the remaining 15 sites, three individual samples were collected at one of the stations, while the other two stations were sampled once as per the protocol used in the first 30 sites. A total of 165 samples from San Francisco Bay and 3 from Carr Inlet were tested during the survey. The sediment samples were collected during three sampling periods: January 4-5, 1990; January 29-31, 1990; and March 12-15, 1990 (Table 16). Carr Inlet sediments were sampled and tested during each period.

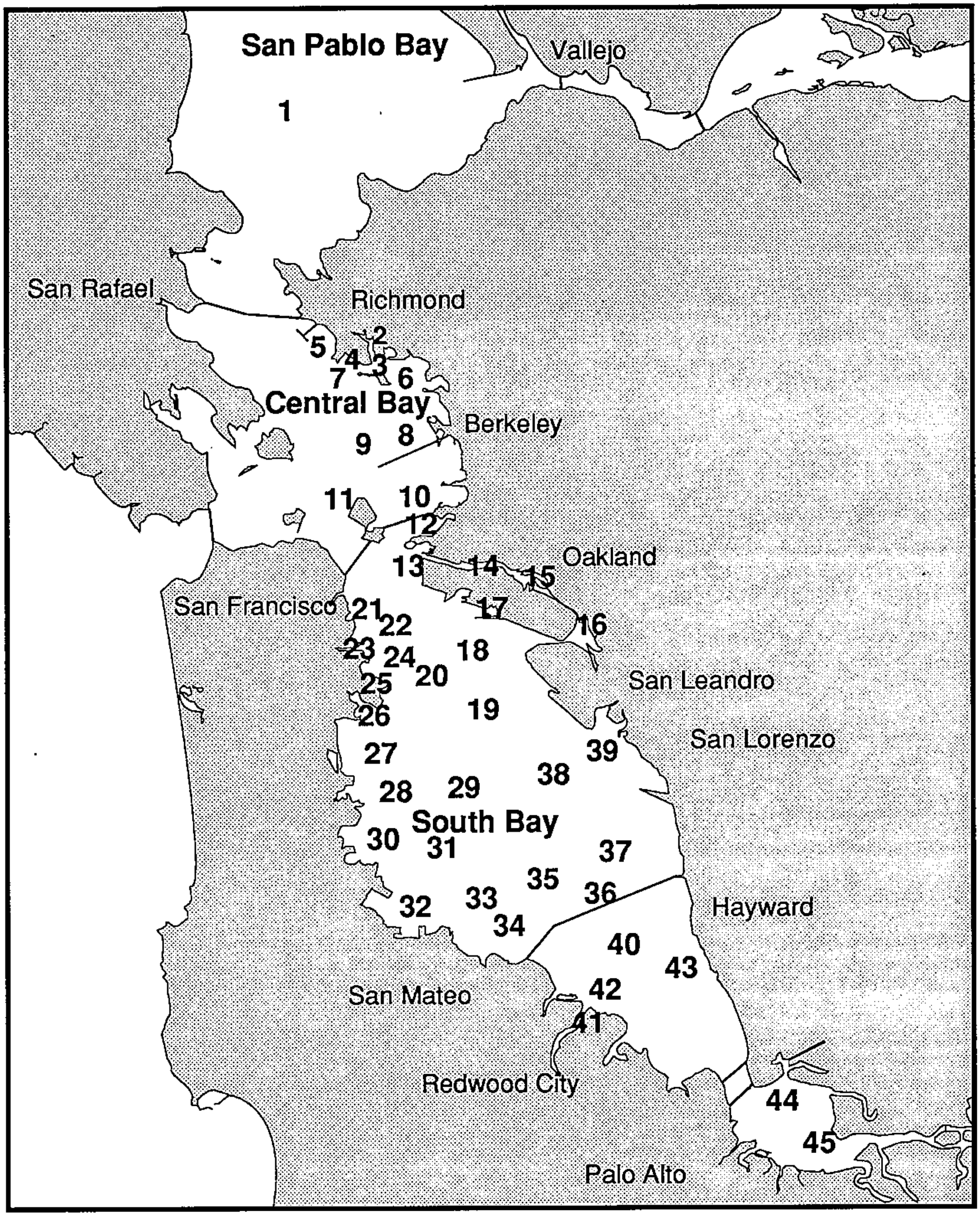

Figure 13. Locations of 1990 sediment toxicity survey sampling sites.

Table 16. Sediment collection dates and coordinates.

Site No.	Site Location	Date Collected	North Latitude	West Longitude
1	San Pablo Bay	1/29/90	38°03'30"	122°24'00"
2	Inner Richmond Harbor	1/29/90	37°55'15"	122°21'58"
3A-1, B, C*	Inner Richmond Harbor	1/5/90	37°54'22"	122°21'30"
3A-2, A-3	Inner Richmond Harbor	1/29/90	37°54'22"	122°21'30"
4A-1, B, C*	Outer Richmond Harbor	1/5/90	37°54'24"	122°22'37"
4A-2, A-3	Outer Richmond Harbor	1/29/90	37°54'24"	122°22'37"
5	Outer Richmond Harbor	1/5/90	37°55'00"	122°24'10"
6	Point Isabel	1/5/90	37°53'50"	122°20'30"
7	Point Isabel	1/5/90	37°53'30"	122°22'45"
8	Berkeley	1/5/90	37°52'00"	122°20'00"
9	Berkeley	1/5/90	37°51'30"	122°22'30"
10	Emeryville	1/5/90	37°50'10"	122°19'13"
11	Emeryville	1/5/90	37°50'08"	122°22'55"
12	Oakland Outer Harbor	1/29/90	37°49'06"	122°19'15"
13	off Alameda NAS	1/30/90	37°47'25"	122°20'13"
14	Oakland Inner Harbor	1/30/90	37°47'31"	122°17'36"
15	Oakland Inner Harbor	1/30/90	37°47'00"	122°15'40"
16	San Leandro Bay	1/30/90	37°45'15"	122°13'23"
17	Alameda Naval Base	3/12/90	37°46'06"	122°18'00"
18	off Alameda	3/13/90	37°44'58"	122°18'15"
19	off San Leandro	3/13/90	37°42'53"	122°17'13"
20	off India Basin	3/12/90	37°44'10"	122°20'36"
21	China Basin	3/12/90	37°46'42"	122°23'05"
22	China Basin	3/12/90	37°46'42"	122°23'05"
23	Islais Creek	3/12/90	37°44'51"	122°22'55"
24	Islais Creek	3/12/90	37°44'56"	122°22'00"
25	India Basin	3/12/90	37°44'05"	122°22'10"
26	Hunters Point	3/12/90	37°42'57"	122°22'22"
27	Hunters Point	3/12/90	37°42'06"	122°21'35"
28	Sierra Point	3/13/90	37°40'06"	122°22'20"
29	Sierra Point	3/13/90	37°41'12"	122°19'17"
30	San Bruno	3/15/90	37°38'25"	122°22'00"
31	San Bruno	3/13/90	37°38'25"	122°20'00"
32	SFO airport	3/13/90	37°36'34"	122°20'22"
33	SFO/San Mateo	3/15/90	37°36'30"	122°17'52"
34	Coyote Point	3/15/90	37°35'49"	122°16'30"
35	Coyote Point	3/15/90	37°37'20"	122°14'45"
36	San Mateo	3/15/90	37°36'20"	122°14'30"
37	San Mateo	3/15/90	37°38'04"	122°12'47"
38	San Lorenzo	3/13/90	37°40'00"	122°15'45"
39	San Lorenzo	3/13/90	37°40'59"	122°14'06"
40	South Bay	1/4/90	37°34'50"	122°13'00"
41A-1, B, C*	Redwood Creek	1/4/90	37°31'00"	122°12'25"
41A-2, A-3	Redwood Creek	1/31/90	37°31'00"	122°12'25"
42A-1, B, C*	Redwood Creek	1/4/90	37°31'58"	122°11'32"
42A-2, A-3	Redwood Creek	1/31/90	37°31'58"	122°11'32"
43A-1, B, C*	South Bay	1/4/90	37°32'43"	122°10'05"
43A-2, A-3	South Bay	1/31/90	37°32'43"	122°10'05"
44	Coyote Creek	1/4/90	37°29'30"	122°06'17"
45	Coyote Creek	1/4/90	37°28'02"	122°03'37"

*Two of the individual replicate samples at station A within sites 3, 4, 41, 42, and 43 were mistakenly collected during different sampling periods than the other samples.

Sediment samples were collected from the research vessel *Prophesy* by use of a 316 stainless steel Gray-O'Hara 0.125 meter square box core. One deployment of the box core at each station provided about 1 liter of sediment for all of the tests. Following retrieval of the box core at each station, a teflon liner was inserted into the box core, the box core was lifted away from the liner, and the upper 2 centimeters of sediment were removed with a teflon-lined scoop. The samples were retained in pre-cleaned glass jars, capped with teflon-lined lids, stored on ice, and transported each evening to the ToxScan, Inc. laboratories. All samples were stored in a temperature-controlled room at 4° C for a period not exceeding 10 days until testing was begun.

Between sampling sites, all sampling equipment was successively rinsed with clean seawater, hexane, deionized water, acetone, deionized water and seawater to avoid cross contamination of samples. The sampling equipment was rinsed with seawater only between stations at each site.

The engine exhaust system on the stern of the sampling vessel was modified to avoid contamination of the samples.

Positioning of the research vessel was accomplished by use of a Trimble Satellite Global Positioning System (GPS). The accuracy of the GPS was ± 3 to 5 meters. At each sampling site, the vessel was positioned at the specified coordinates and a marker buoy dropped, designating the site center. The three stations at each site were located in a triangular configuration 15 to 30 meters in radius around the site center.

Sediment Subsampling

Portions of each sample for the different tests were subsampled with a teflon spatula. The spatula was rinsed with acetone and deionized water between samples. After homogenization subsamples were apportioned for each test:

- 180 grams weighed into 1-liter jars for the bivalve and echinoderm embryo tests;
- 30 grams weighed into 50-ml glass centrifuge tubes with teflon-lined screw caps for the Microtox™ (saline extract) tests;
- 3.3 grams weighed into 50-ml glass centrifuge tubes with teflon-lined screw caps for preparation of Microtox™ (organic extract) test;
- and 400 ml aliquots measured into 500 ml. teflon bottles and frozen at -20° C for possible future chemical analyses. These aliquots were eventually transferred to the San Francisco Bay Regional Water Quality Control Board for chemical analyses.

Bivalve Embryo Bioassay

Adult *M. edulis* were collected in Elkhorn Slough in Monterey County, California and spawned. The fertilized embryos were exposed to elutriates prepared from the sediments. The endpoints of survival, abnormal morphological development, and cytogenetic abnormalities were quantified.

Elutriates were prepared by adding 180 grams (wet weight) of the samples to pre-cleaned 1-liter jars and bringing the total volume in each jar up to 900 ml with filtered, UV-treated seawater (EPA/ACOE, 1977). The sediment-water mixtures were shaken vigorously for 30 minutes and allowed to settle undisturbed for 1 to 3 hours until the overlying supernatant was relatively clear. The supernatant was poured off and diluted 1:1 with clean seawater to provide the 50 percent solution to which the embryos were exposed. Unacceptably high mortality and abnormal development in control sediments were observed in pre-survey tests of the undiluted (100%) suspensions and not in the 50 percent diluted samples; therefore, the tests were performed with the diluted samples. The data from the 1990 synoptic survey, therefore, are equivalent to those historical data evaluated in chapter 2 as "50% diluted suspension."

Adult mussels were induced to spawn by high-temperature stimulation. Eggs and sperm were collected in separate basins filled with aerated seawater at 25°C. Egg density was determined by microscopically counting several 1-ml aliquots taken from the well-mixed egg basin. Fertilization was confirmed by microscopic examination.

Mussel embryos were exposed to about 200 ml of elutriate in 250-ml glass dishes. Aliquots of about 5,400 embryos were tested in each dish for an embryo density of about 27 per ml. Samples from each sampling station were tested without laboratory replication.

Following a 48-hour exposure, the contents of each dish were poured through a 45-micron nytex screen. Surviving embryos were retained on the screen. The test dishes were rinsed three times with seawater and each successive rinse was poured through the screen to ensure complete transfer of embryos. The embryos were quantitatively transferred from the screen into a graduated cylinder and the volume was adjusted with a seawater-formalin mixture. Contents of the cylinder were mixed by inversion to ensure uniform distribution of embryos, and a 1-ml aliquot was transferred to a Sedgwick-Rafter counting slide for microscopic evaluation. Percent survival was determined as the quotient of the final embryo density divided by the density in the respective batch seawater control and multiplied by 100. The percent of the surviving embryos that appeared to be morphologically normal was determined. Embryos were scored as normal if they possessed a complete larval shell with a fully developed hinge (ASTM, 1980). A positive control toxicant (CuSO4) was tested in a similar manner in 200-ml volumes of test solution.

In addition to the usual biological endpoints of percent survival and percent normal development, the percent of the embryos with cytogenetic abnormalities was determined by Dr. Jo Ellen Hose (Occidental College). Cytogenetic endpoints had been determined in sediment toxicity tests with echinoderm embryos (Long *et al.*, 1989) and an attempt was made to determine if bivalve larvae responded similarly to echinoderm larvae when exposed to sediments that may contain mutagenic compounds.

For the cytogenetic analyses, the embryos were stained with an aceto-orcein stain, transferred to glass microscope slides, covered with cover slips, examined under oil immersion with a microscope, and the number and type of mitotic aberrations observed among 50 anaphase-telophase mitotic figures were noted following Hose (1985). The number of embryos examined to yield 35 telophase figures also was recorded. Three samples from each site and the Carr Inlet fontrol were tested with no laboratory replication.

Echinoderm Embryo Bioassay

Aliquots of the elutriates prepared for the bivalve embryo tests were also tested with echinoderm embryos to determine the incidence of cytogenetic endpoints following the methods of Hose (1985) and Long *et al.* (1990). The elutriates were not diluted to 50 percent as in the bivalve bioassays; rather, they were used full-strength.

Adult *S. purpuratus* were collected from intertidal areas near Davenport, California and held for at least 3 months. They were induced to spawn by injection of 0.5 ml of 0.5 M KCl. Fertilization was conducted with a sperm:egg ratio of 500:1. A density of about 30 embryos per ml of elutriate solution was used in the tests that were conducted in 200-ml glass jars. The bioassays proceeded for 48 hours at 15°C, after which the embryos were mixed to produce a uniform suspension in the test jars and 10 ml were removed. Buffered formalin was added to kill and preserve the embryos. All test sites and Carr Inlet controls were tested in triplicate. The cytogenetic evaluations followed the procedures developed by Dr. Jo Ellen Hose (Occidental College) as reported in Hose (1985) and Long *et al.* (1990). Seven embryos were examined per sample for all mitotic figures and aberrations.

Microtox™ (Saline Extract) Bioassay

Sample extractions followed the protocols of Tetra Tech, Inc. and E.V.S. Consultants (1986). Thirty-gram aliquots of each sample were placed in a 50-ml glass centrifuge tubes and 10 ml of the Microtox™ diluent (2.0% NaCl w/v in double-distilled organic-free water) was added. The solutions were briefly shaken manually, then placed on a rotary shaker (100 rpm) for 24 hours in the dark at 4°C. Then the samples were centrifuged for 15 minutes at 5000 rpm and the supernatant poured off into clean 20-ml glass vial having teflon-lined screw caps and stored at 4°C until testing began.

Each saline extract was subjected to a screening procedure in which the highest concentration was initially tested (equivalent to 1500 mg sediment/ml extract); and, if no reduction in light production was observed, further testing was not conducted on the sample. The toxicity tests involved the following procedures:

- The freeze-dried bacteria *Photobacterium phosphoreum* were rehydrated with 1.0 ml of reconstitution solution, covered with parafilm, stored at 4°C, and tested within 5 hours of rehydration;
- 50 and 0 percent dilutions of the sediment supernatant in Microtox™ diluent were prepared, using the 0 percent dilution as a reagant blank needed to measure spontaneous decay in bacterial luminescence independent of any treatment;
- In each test cuvette, 10 microliters of the rehydrated bacterial suspension were added to 500 microliters of diluent and incubated for 15 minutes in one of the 15°C wells on the Microtox™ analyzer and initial luminescence was measured;
- At regular intervals, 500 microliter aliquots of each supernatant dilution were added to one of the cuvettes;
- Exactly 5 and 15 minutes after addition of the sediment supernatants, luminescence was measured at the same interval and in the same sequence used for supernatant additions in the preceding step; and
- Percent decrease in luminescence was calculated relative to the reagant blank, using the formula:

$$\text{Percent decrease} = [(RI_o - I_t)/RI_o)] \times 100,$$

where: I_o = initial luminescence,
It = luminescence at the end of 15 minutes, and
R = blank ratio.

The blank ratio was calculated by: R = Bt/Bo,

where: Bo = initial luminescence of the reagant blank, and
Bt = luminescence of the reagant blank after 15 minutes.

Phenol was tested at least daily as a standard reference toxicant. The chart below lists the results of testing this chemical :

Date	EC50 (mg/L)	95% confidence limits
1/10/90	15.5	12.7, 19.0
1/11/90	15.7	14.5, 17.1
1/11/90	18.7	16.4, 21.4
1/12/90	17.6	15.5, 20.0
2/3/90	16.5	14.6, 18.7
2/4/90	19.2	17.1, 21.5
2/8/90	14.7	12.5, 17.3
3/19/90	23.2	22.8, 23.7
3/24/90	26.2	22.8, 30.1

Microtox™ (Organic Extract) Bioassays

The organic extract procedures also followed the basic protocols of Tetra Tech, Inc. and E.V.S. Consultant, 1986. They involved the following steps:

- The 3.3-gram sediment aliquots were placed into 50-ml Pyrex centrifuge tubes, centrifuged for 5 minutes, and the water removed.
- 15 grams of sodium sulfate was added and mixed thoroughly; then, 30-ml dichloromethane (DCM) was added and mixed.
- The mixture was shaken for 10 seconds, vented, and tumbled overnight, centrifuged 5 minutes, and poured into a 100-ml glass bottle.
- The DCM extraction was repeated twice and the three extracts were combined in a Kuderna-Danish flask and attached to a Snyder column and concentrated to a final volume of <10 mL.
- 25-30 ml of undenatured ethanol were added and the extract concentrated again in a Snyder column at 100°C. Final extract volume was 10 mL.
- The freeze-dried bacteria were rehydrated with 1 ml of reconstitution solution, covered with parafilm, stored at 4°C, and used within 5 hours of hydration.
- The sediment extract was diluted 1:100 with Microtox™ diluent, resulting in a stock solution for testing containing 1 percent ethanol, and equivalent to 3.3 mg of sediment per ml of solution.
- Serial dilutions of 50, 25, 12.5, 6.25, 3.13, 1.56, and 0 percent stock solution were prepared (the 0% solution was the reagant blank).
- In each of the seven cuvettes, 20 microliters of the rehydrated bacterial suspension was added to 500 microliters of diluent containing ethanol and incubated for 15 minutes after which initial luminescence was measured.
- At regular intervals, 500-microliter aliquots of each extract dilution were added to one of the cuvettes, allowed to incubate for 5 minutes, after which the final luminescence was measured.
- The percent decrease in luminescence relative to the reagant blank was calculated using the same formula used for the saline extract tests.

The organic extracts of each sample were tested first with the highest test concentration. Samples in which gamma values did not exceed 0.250 were not tested further since previous experience had demonstrated that it was not possible to calculate an EC_{50} with these small gamma values. Those extracts which showed light reductions (gamma values of >0.250) were tested with the dilution series listed above. In many cases, even if a 50 percent light reduction was not achieved at the highest concentration tested, the Microtox™ software was able to extrapolate an EC_{50} value for the sample with reasonable confidence limits. In some cases, however, no EC_{50} could be calculated and, where this occurred, the EC_{50} was reported in Appendix B as >1.65 mg/ml.

Each dilution of each sample was tested without replication. The Microtox™ software calculated the EC_{50} and 95 percent confidence limits, based upon closeness of the observed data to the predicted regression line for the dilution series.

Phenol was tested at least daily as a reference toxicant for the tests. The following chart summarizes the results:

Date	EC_{50} (mg/L)	95% Confidence Limits
1/10/90	15.5	12.7, 19.0
1/11/90	15.7	14.5, 17.1
1/11/90	18.7	16.4, 21.4
1/12/90	17.6	15.5, 20.0
1/13/90	19.4	14.0, 26.7
2/8/90	14.7	12.5, 17.3
2/9/90	17.6	17.0, 18.1
2/10/90	15.3	14.5, 16.2
2/11/90	15.4	12.9, 18.5
2/12/90	19.7	16.7, 23.1
3/22/90	25.6	23.9, 27.5
3/23/90	20.2	17.2, 23.8
3/25/90	28.1	27.3, 28.9
3/28/90	24.0	20.3, 28.4

Statistical Analyses

The data from the three sampling periods were evaluated separately to identify sites that were significantly different (more toxic) than the respective controls. Data from the Microtox™ tests of the saline extracts were not statistically evaluated, since none of the gamma values were sufficiently different (positive) from the blanks, therefore precluding the calculation of EC_{50}s.

All of the data sets were tested for normality with a Lilliefors test, a variation of the Kolmogorov-Smirnov test for normality (Wilkinson, 1989). Normal probability plots of each data set for each sampling period were also prepared and examined. In the cases of percent data, data were angular (arcsin) transformed before examination. The assumption of normality was assumed to have been met if a data set tested as normal and appeared normal when plotted. Variance homogeneity of the samples taken during the three sampling periods was tested according to Bartlett's test (Sokal and Rohlf, 1981).

Whenever the appropriate assumptions of normality and homogeneity of the variances of the underlying distributions appeared to have been met, parametric tests were used to evaluate data from each sampling period. Measures of percent mussel survival and percent abnormality, as well as urchin mitotic rate were analyzed using one-way parametric analysis of variance (ANOVA). Because the site-to-control comparisons were planned as a part of the study design, site means significantly different from control means were identified by comparisons against the least significant difference calculated for each sampling period (Steele and Torrie, 1980).

In several data sets, variances appeared heterogeneous and/or the data set appeared not to have a normal distribution. In these cases, the data were analyzed using the Kruskal-Wallis nonparametric test (Wilkinson, 1989). Nonparametric multiple comparisons of site means against control means were then made according to procedures described by Zar (1984), using Dunnett's q' as the critical value. Data sets analyzed in this manner included results of assays of numbers of embryos with more than one cytologic abnormality and more than one micronucleus in the urchin tests and mussel mitotic rate (numbers of embryos per 35 telophases). The results of the Microtox™ tests of organic extracts were analyzed using a chi-square test.

RESULTS

The data from each of the toxicity tests are listed in Appendix B for each station and replicate. The results of testing the positive and negative controls also are listed in Appendix B.

Mussel Embryo Survival and Abnormal Development

Tests of abnormal development and survival were performed with each of the 165 samples and the Carr Inlet controls. The arithmetic means and standard deviations for each sampling site are summarized in Table 17. At those sites (numbers 3, 4, 41, 42, and 43) in which the samples from one station at the site were collected during two different sampling periods, the means were calculated only with the data collected during the same sampling period; the data from the other sampling period were ignored. At the other 10 sites (indicated with superscript b in Table 17) in which three samples were collected at one of the stations, the mean value was calculated for the replicated station and that mean was used along with the unreplicated data from the other two stations to determine the site mean.

The data from the tests of the Carr Inlet control sediments indicated that the mussel embryos performed relatively poorly in the period 2 tests. Mean percent survival was relatively low (72.6%) and the percent abnormal development was relatively high (10.6%) in the Control 2 sediments. In the seawater controls, mean survival in periods 1, 2, and 3 were very high (92.8%, 92.1%, and 88.8%, respectively). However, mean percent abnormal development in seawater controls was relatively high in the second period (9.9%) as compared to the first and third periods (1.6% and 3.3%, respectively).

Analyses of variance (ANOVA) indicated that among-site differences in mean percent abnormal development were not significant in period 1 (either no abnormals or very few) and period 3 ($p = .206$), but were highly significant in period 2 ($p = 0.000$). Mean percent abnormal development was significantly higher ($\alpha = 0.05$) than respective sediment controls in only four sites (Figure 14):

- Site 1 (San Pablo Bay).
- Site 13 (off the Alameda NAS).
- Site 15 (upper Oakland Inner Harbor).
- Site 16 (San Leandro Bay).

All four of these sites were tested in the second period, during which the embryos performed relatively poorly in the controls. Among these four sites, site 15 was most toxic as indicated by the highest incidence of abnormal development.

ANOVA indicated that among-site differences in mean survival were not significant in period 1 ($p = 0.066$) and period 2 ($p = 0.86$), but were significant in period 3 ($p = 0.009$). Mean percent survival was significantly lower ($\alpha = 0.05$) than respective sediment controls at only five sites (Figure 14): Sites 30 (off San Bruno); 32 (southeast of San Francisco Airport); 33 (off Coyote Point, southeast of San Francisco Airport); 38 (off San Lorenzo); and 39 (off San Lorenzo-San Leandro Marina). Among these five sites, sites 32 and 38 were most toxic, as indicated by this endpoint. All five sites were tested during the third period.

Mean survival in many of the samples was higher than that in the controls; therefore, percent survival was indicated as greater than 100 percent for some sites in Table 17. Survival was determined by dividing the numbers of survivors in the test samples by the numbers of survivors in the seawater controls. If the numbers of survivors in the test samples were greater than those in the controls, the percent survival appeared as greater than 100 percent.

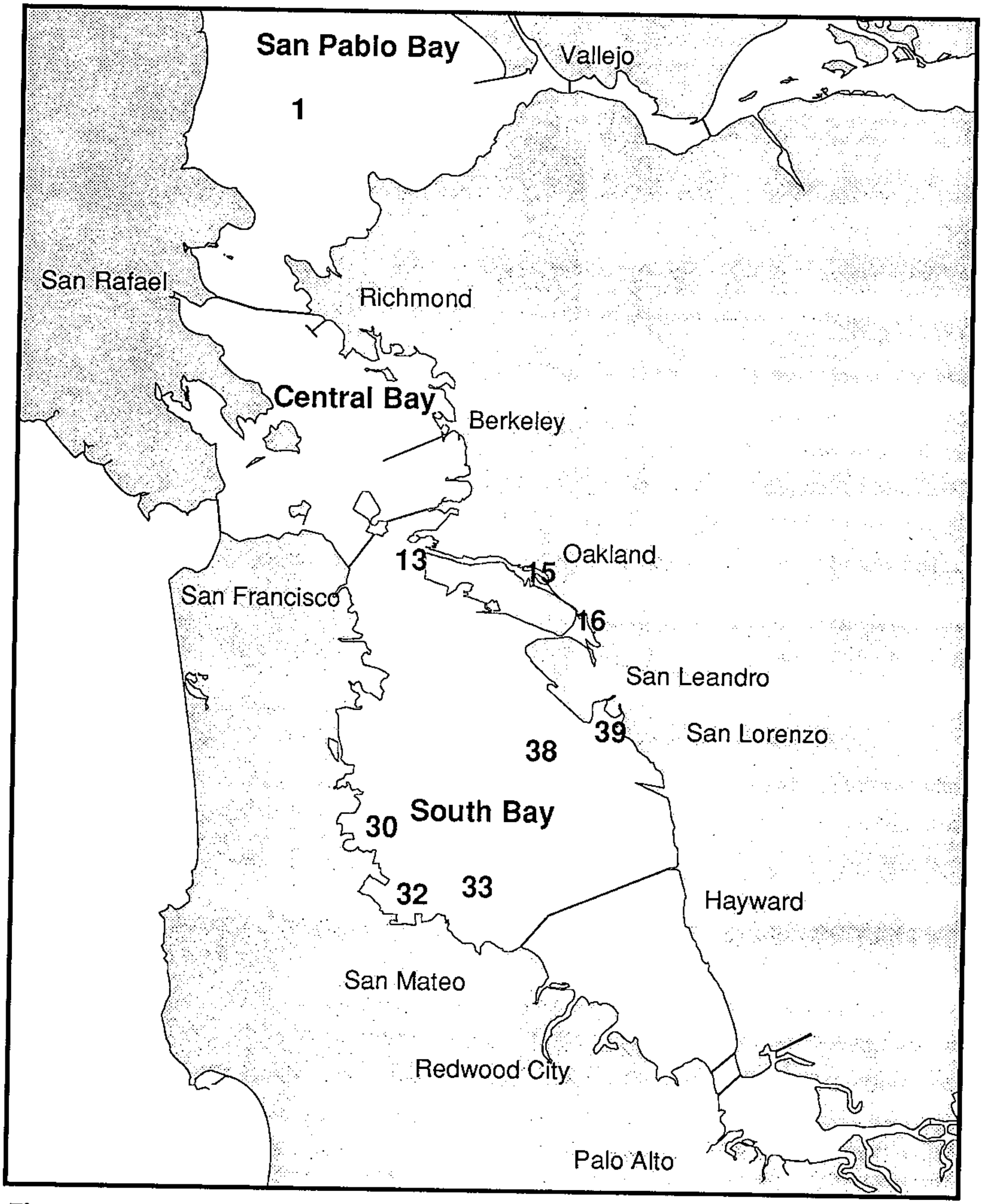

Figure 14. Sampling sites in which sediments were significantly toxic to bivalve larvae normal development or survival.

Table 17. Average (± standard deviation) percent survival and abnormal development in *M. edulis* larvae exposed to suspended sediments from 45 sites in San Francisco Bay. * An asterisk indicates that the test results were significantly different (more toxic) than respective controls (α = 0.05).

Sampling Period	Site Number	Percent Survival [a]	Percent Abnormal
1	3	102.8 ± 0.8	0.5 ± 0.5
1	4	93.8 ± 14.2	1.0 ± 1.1
1	5	103.2 ± 11.7	0.2 ± 0.4
1	6	100.9 ± 7.2	0.3 ± 0.5
1	7	118.3 ± 9.3	0.0 ± 0.0
1	8	103.1 ± 8.1	0.0 ± 0.0
1	9	97.2 ± 4.9	0.0 ± 0.0
1	10	112.8 ± 6.8	0.0 ± 0.0
1	11	118.2 ± 8.2	0.0 ± 0.0
1	40	95.8 ± 23.2	0.0 ± 0.0
1	41	106.3 ± 9.2	0.0 ± 0.0
1	42	114.9 ± 6.6	0.0 ± 0.0
1	43	117.3 ± 14.5	0.0 ± 0.0
1	44	117.3 ± 13.7	0.0 ± 0.0
1	45	113.8 ± 14.3	0.3 ± 0.5
1	Carr Inlet Control 1	100.4 ± 9.3	0.2 ± 0.4
2	1 [b]	78.4 ± 14.0	17.4 ± 2.0*
2	2 [b]	84.8 ± 12.8	12.2 ± 0.3
2	12	77.0 ± 12.2	12.7 ± 1.4
2	13 [b]	81.6 ± 8.5	14.5 ± 2.4*
2	14 [b]	79.8 ± 13.5	13.1 ± 0.4
2	15 [b]	80.0 ± 6.4	18.8 ± 2.3*
2	16	79.1 ± 11.7	14.3 ± 1.2*
2	Carr Inlet Control 2	72.6 ± 4.4	10.6 ± 1.9
3	17	105.3 ± 14.6	5.7 ± 2.7
3	18	105.6 ± 8.0	3.3 ± 1.2
3	19 [b]	103.4 ± 15.0	5.6 ± 4.1
3	20	98.3 ± 20.7	7.5 ± 3.3
3	21 [b]	116.2 ± 15.3	5.6 ± 0.9
3	22	125.7 ± 19.4	6.7 ± 3.1
3	23 [b]	126.6 ± 6.7	6.0 ± 2.1
3	24 [b]	109.0 ± 34.4	5.2 ± 3.4
3	25	124.8 ± 19.0	8.3 ± 3.9
3	26	107.8 ± 3.4	7.9 ± 2.7
3	27	102.7 ± 20.1	6.2 ± 2.1
3	28	114.2 ± 16.8	6.7 ± 1.7
3	29	104.2 ± 12.5	10.7 ± 4.6
3	30	85.7 ± 19.8*	11.6 ± 2.8

Table 17 (continued)

Sampling Period	Site Number	Percent Survival [a]	Percent Abnormal
3	31[b]	92.9 ± 9.2	8.4 ± 5.0
3	32	81.9 ± 19.7*	6.5 ± 1.0
3	33	88.2 ± 12.4*	9.6 ± 2.5
3	34	127.0 ± 19.6	7.3 ± 2.6
3	35	115.2 ± 18.2	10.9 ± 2.6
3	36	108.3 ± 2.4	3.9 ± 1.0
3	37	112.1 ± 16.0	7.0 ± 2.1
3	38	81.4 ± 19.9*	7.8 ± 5.6
3	39	88.2 ± 10.1*	7.0 ± 3.8
3	Carr Inlet Control 3	113.0 ± 5.9	6.8 ± 1.8

[a] Percent survival relative to mean seawater control data.
[b] Three samples were collected at one of the stations and the station mean was used to determine the site mean.

Some of the regions sampled in the 1990 synoptic survey had been sampled previously in the historical studies summarized in chapter 2 (Table 6) and tested with bivalve larvae exposed to 50 percent dilutions, *i.e.*, the same methods used in the 1990 survey. The following chart shows that in some of these areas there was very good agreement between the previous results and the 1990 results:

Geographic Area	Average percent abnormality among bivalve larvae: Historical surveys	1990 survey
San Pablo Bay	19.5 ± 19, n=4	17.4 ± 2.0, n=3
Central Bay	2.7, n=1	0.1 ± 0.2, n=15
Oakland Inner Harbor	16.9 ± 22.7, n=24	16.0 ± 4.0, n=6
Oakland Outer Harbor	14.3 ± 25.2, n=14	12.7 ± 1.4, n=3
Alameda Naval Base	4.0, n=1	5.7 ± 2.7, n=3

In some other regions, the agreement was relatively poor between the historical data and the 1990 data as the following chart shows:

Geographic Area	Average percent abnormality among bivalve larvae: Historical surveys	1990 survey
South Bay, southern part	47.2, n=1	0.2 ± 0.2, n=6
Richmond Harbor	21.0 ± 16.3, n=13	4.6 ± 1.6, n= 9
Redwood Creek	16.8 ± 21.8, n=2	0.0 ± 0.0, n=6
Port of San Francisco	14.7 ± 22.6, n=20	5.4 ± 0.3, n=6

Cytogenetic Effects in Mussel Embryos

An attempt was made to determine cytogenetic endpoints in mussel embryos similar to those that have been previously quantified in urchin embryos (Hose, 1985; Long *et al.*, 1990). Samples from 15 of the 45 sites were selected for the tests, expecting that these samples would represent a gradient in toxicant concentrations. The objectives of this test were (1) to determine the feasibility and sensitivity of this endpoint in mussel embryos and (2) to identify patterns in toxicity, if any. Based upon previous studies, sites 2, 3, 14, 15, 23, and 41 were expected to be the most highly contaminated; sites 4, 13, 21, 24, 42, and 43 were expected to be moderately contaminated; and sites 1, 19, and 31 were expected to be least contaminated as were the control sediments from Carr Inlet.

Results of the cytogenetic examinations of the mussel embryos exposed to sediments from 15 of the sites are summarized in Table 18. Data for three cytogenetic endpoints are presented as averages of the three samples tested per site: (1) the number of embryos examined to find 35 cells that were in telophase, an estimate of the mitotic activity of the embryos; (2) percent of the telophases that were aberrant; and (3) the number of normal telophases observed per embryo. Based upon the results of each of the endpoints, each site was ranked (where a rank of 1 indicates highest toxicity).

Table 18. Average results (± standard deviation for three samples per site) of cytogenetic analyses of mussel larvae (*M. edulis*) exposed to suspended sediments from 15 sites. The numbers in parentheses are site ranks based upon average results for each site.

Sampling Period	Site Number	Embryos per 35 Telophases		Percent Aberrant Telophases		Normal Telophases per Embryo	
1	3	123 ± 25	(10)	50.0 ± 10.0**	(3)	0.156 ± .034	(9)
1	4	123 ± 28	(10)	28.3 ± 14.3*	(15)	0.177 ± .038	(10)
1	41	158 ± 9.3	(7)	46.0 ± 5.3**	(4)	0.120 ± .005	(6)
1	42	89 ± 16	(13)	31.4 ± 13.1*	(10)	0.278 ± .018	(14)
1	43	69 ± 1	(15)	41.9 ± 4.4**	(6)	0.295 ± .027	(15)
Control 1		92 ± 9		9.5 ± 4.4		0.346 ± .034	
2	13	232 ± 79*	(2)	41.7 ± 10.5**	(8)	0.097 ± .041	(3)
2	14	73 ± 9	(14)	53.4 ± 8.3**	(2)	0.230 ± .063	(13)
2	1	130 ± 19	(9)	22.7 ± 3.9*	14)	0.216 ± .030	(12)
2	2	122 ± 21	(12)	32.3 ±14.5**	(9)	0.201 ± .066	(11)
2	15	172 ± 21	(5)	45.6 ± 4.6**	(5)	0.111 ± .005	(5)
Control 2		95 ± 12		8.6 ± 2.9		0.342 ± .050	
3	19	133 ± 11	(8)	59.6 ± 7.9**	(1)	0.106 ± .013	(4)
3	21	311 ± 115**	(1)	30.1 ± 8.8**	(11)	0.089 ± .042	(1)
3	23	230 ± 44*	(3)	41.8 ± 11.5**	(7)	0.092 ± .030	(2)
3	24	171 ± 8	(6)	27.1 ± 9.1**	(12)	0.150 ± .022	(8)
3	31	175 ± 8	(4)	26.4 ± 2.6**	(13)	0.147 ± .009	(7)
Control 3		83 ± 6		4.8 ± 3.3		0.404 ± .022	

*Significantly different from respective sediment controls at $\alpha = 0.05$.
**Significantly different from respective sediment controls at $\alpha = 0.01$.

The three tests of the Carr Inlet control sediment indicated arithmetic averages of 92, 95, and 83 embryos per 35 telophases. High values are indicative of a toxic response, *i.e.*, more embryos had to be counted in order to find 35 cells in telophase. Nonparametric Kruskal-Wallis one-way ANOVA indicated that results were significantly different in sampling periods 2 and 3, but not in period 1. Results were significant ($\alpha = 0.05$) in embryos exposed to sediment from sites 13 (off Alameda), 21 (China Basin), and 23 (Islais Creek). Also, results for site 21 were significant at the 0.01 level.

Control sediments caused 9.5, 8.6, and 4.8 percent aberrant telophases. Variability among sites for this endpoint were highly significant during all three sampling periods ($p = 0.00$ to 0.001). Mean percent aberrant telophases in embryos exposed to sediments from all 15 sites were significantly higher than control ($\alpha = 0.05$) means. Also, the results were significant at $\alpha = 0.01$ for all of the sites, except sites 1, 4, and 42. The mean percent aberrant telophases were highest in embryos exposed to sediments from sites 3, 14, 19, and 41 which were located in Inner Richmond Harbor, Oakland Inner Harbor, northern part of South Bay, and Redwood Creek, respectively.

Embryos exposed to the three control sediments had 0.346, 0.342, and 0.404 normal telephases per embryo, all of which were greater than the results with the samples from the 15 San Francisco Bay sites. The numbers of normal telophases per embryo were lowest in embryos exposed to sediments from sites 13, 15, 19, 21, 23, and 41 located off Alameda, in Oakland Inner Harbor, northern Central Bay, China Basin, Islais Creek, and Redwood Creek, respectively. Since this endpoint was the reciprocal of the percent aberrant telophase endpoint, no statistical treatment of the data was conducted.

Sediments from all 15 sites were significantly toxic to at least one of the endpoints in these tests (Figure 15). Sediments from sites 13 (off Alameda), 21 (China Basin), and 23 (Islais Creek) caused significant decreases in mitotic activity, highly significant increases in percent aberrant telophases, and relatively low numbers of normal telophases per embryo; therefore, they appear to have been most toxic to these endpoints. Overall, sediments from sites 1, 4, and 42 appear to have been among the least toxic.

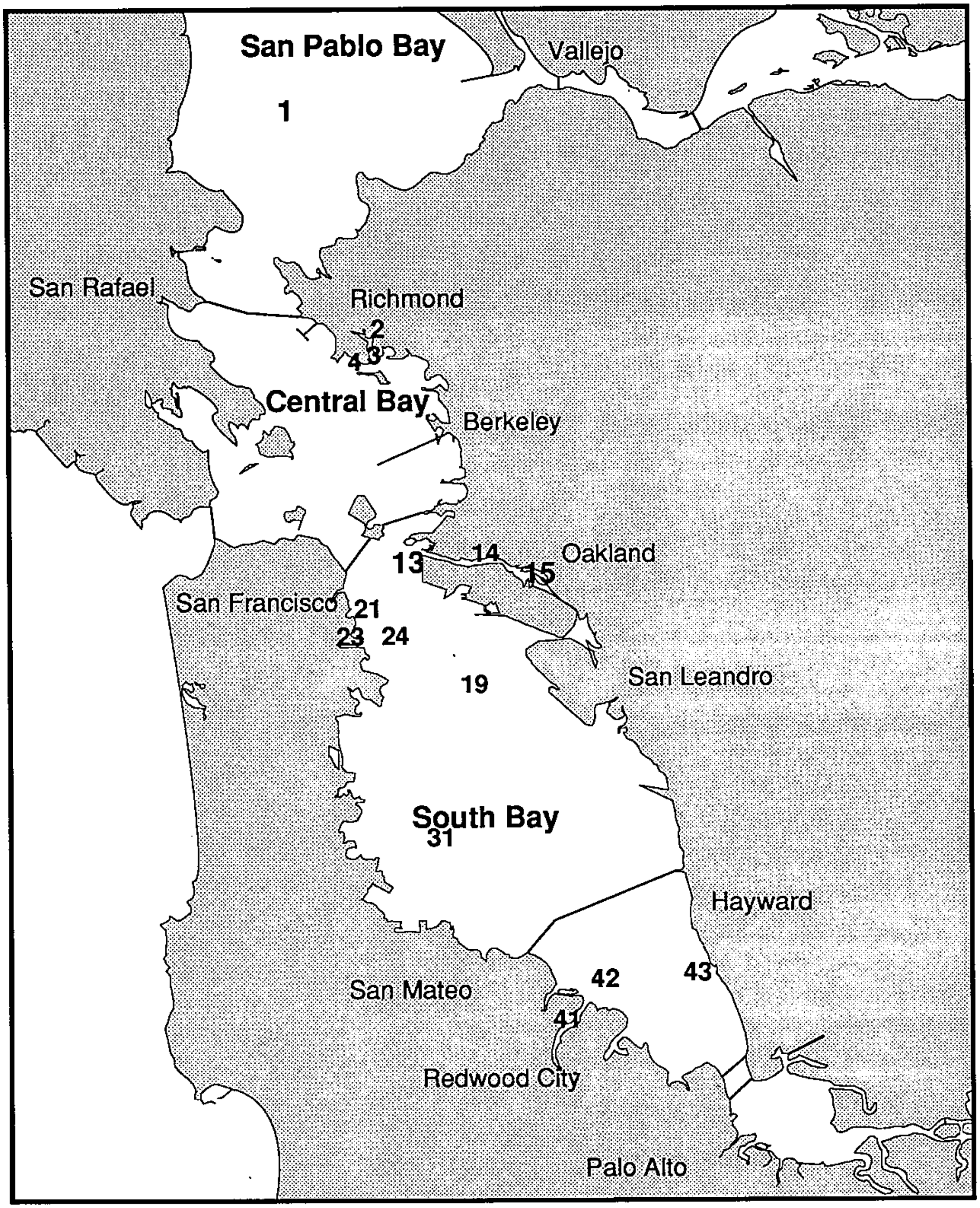

Figure 15. Sampling sites in which significant cytogenetic effects were observed in mussel embryos *(M. edulis)*.

Cytogenetic Effects in Urchin Embryos

To provide a basis for comparison of the results of the cytogenetic endpoints in the mussel embryo tests, similar endpoints were quantified in the urchin embryos, using methods that had been used previously (Hose, 1985; Long *et al.*, 1990). As in the mussel embryo cytogenetic tests, these tests also were performed with sediments from 15 of the sites. The 15 sites were the same as those tested with the mussel embryos.

Table 19 summarizes the results of four cytogenetic endpoints: (a) number of mitoses per embryo, an indicator of mitotic rate; (b) percent incidence of aberrant telophases; (c) number of embryos with more than one micronucleus; and (d) number of embryos with more than one cytologic abnormality. The incidence of abnormal cytologic disorders generally was lower in embryos exposed to the controls than in the embryos exposed to the 15 San Francisco Bay samples.

The arithmetic averages of the mitotic activities in the embryos exposed to the controls were 10.4, 10.9, and 11.7 (Table 19). Variability among sites for this endpoint was highly significant during all three sampling periods ($p = 0.001$ to 0.021). Mitotic activity was significantly lower ($\alpha = 0.05$) in embryos exposed to sediments from 9 of the 15 sites. These sites were located in Richmond Harbor, off Alameda, Oakland Inner Harbor, Islais Creek, and Redwood Creek. At the 0.01 level of significance, the results were lower in embryos exposed to sediments from sites 23 (Islais Creek) and 42 (Redwood Creek).

The average percent incidences of aberrant telophases in embryos exposed to the controls were 6.9, 7.7, and 8.0. Average percent incidences of aberrant telophases were highest in embryos exposed to sediments from sites 19, 24, 21, 15, and 14 located in northern South Bay, off Islais Creek, China Basin, upper Oakland Inner Harbor, and lower Oakland Inner Harbor, respectively. ANOVA indicated that variability among sites was highly significant during each sampling period ($p = 0.00$ to 0.003). Sediments from all but sites 1 (San Pablo Bay) and 4 (Outer Richmond Harbor) were significantly different (more toxic) from the control sediments ($\alpha = 0.05$). Also, results for sites 14, 15, 19, and 24 were significant at $\alpha = 0.01$.

None of the embryos exposed to the controls had more than one micronucleus. Non-transformed data were analyzed in a non-parametric Kruskal-Wallis one-way ANOVA to determine if any variability among sites was significant, then non-parametric multiple comparisons of site means against control means were used to identify sites with significant differences from the controls (Zar, 1984). Significant variability in the data were observed in only the first and third sampling periods. Embryos exposed to sediments from sites 3, 19, 21 and 24 had significantly higher incidences of micronuclei than the respective controls ($\alpha = 0.05$). Also, the results for sites 19 and 21 were significant at the 0.01 level.

The cytological abnormality data were analyzed with a non-parametric, Kruskal-Wallis one-way ANOVA. Variability among sites was not significant for any of the three sampling periods ($p= 0.208$ to 0.257). Therefore, none of the samples had incidences of cytological abnormalities that were significantly higher than the respective controls. The arithmetic averages of cytological abnormalities were highest in embryos exposed to samples from sites 19 (off San Leandro) and 21 (China Basin).

The endpoint of percent aberrant telophases was most sensitive of the four that were measured; 13 of 15 sites were determined to be significantly different from controls at $\alpha = 0.05$; and 4 of 15 were significant at $\alpha = 0.01$. The cytological abnormality endpoint was least sensitive; none of the results were identified as significantly different from controls.

Table 19. Average results (± standard deviation for three samples per site) of cytogenetic/cytologic analyses of urchin embryo (*S. purpuratus*) exposed to suspended sediments from 15 sites. The numbers in parentheses are site ranks.

Sampling Period	Site No.	Mitoses per Embryo	Percent Aberrant Telophases	Embryos with >1 Micronuclei	Embryos with >1 cytologic Abnormality
1	3	8.3 ± 1.3* (10)	23.5 ± 10.6* (13)	3.0 ± 1.0* (4)	1.3 ± 1.5 (12)
1	4	8.0 ± 0.8* (7)	13.8 ± 1.2 (14)	1.0 ± 1.0 (10)	1.7 ± 1.1 (11)
1	41	9.1 ± 1.7* (12)	24.8 ± 6.1* (12)	0.0 ± 0.0 (15)	1.0 ± 1.0 (13)
1	42	7.1 ± 0.7** (3)	31.5 ± 7.7* (10)	0.3 ± 0.6 (13)	2.7 ± 1.1 (8)
1	43	9.3 ± 0.7 (13)	28.7 ± 8.6* (11)	0.7 ± 0.6 (12)	0.7 ± 0.6 (15)
	Control 1	11.7 ± 1.0	8.0 ± 1.7	0.0 ± 0.0	2.0 ± 0.0
2	1	9.8 ± 1.1 (14)	12.0 ± 5.0 (15)	0.3 ± 0.6 (13)	2.3 ± 1.5 (10)
2	2	7.4 ± 1.0* (4)	32.5 ± 7.7* (9)	2.0 ± 2.0 (5)	3.0 ± 2.0 (7)
2	13	7.9 ± 1.0* (6)	32.8 ± 16.3* (8)	1.7 ± 0.6 (9)	1.0 ± 1.0 (13)
2	14	7.7 ± 0.7* (5)	43.5 ± 3.2** (5)	2.0 ± 1.0 (5)	4.7 ± 0.6 (6)
2	15	8.0 ± 1.8 (7)	43.7 ± 3.4** (4)	1.0 ± 1.0 (10)	2.7 ± 2.1 (8)
	Control 2	10.4 ± 0.3	6.9 ± 5.8	0.0 ± 0.0	1.0 ± 0.0
3	19	8.2 ± 2.2 (9)	68.3 ±10.0** (1)	6.0 ± 0.0** (1)	7.7 ± 3.2 (1)
3	21	8.8 ± 0.4 (11)	47.4 ± 15.6* (3)	6.0 ± 3.5** (1)	6.0 ± 1.7 (2)
3	23	4.1 ± 0.6** (1)	40.7 ± 11.6* (6)	2.0 ± 1.0 (5)	5.0 ± 1.7 (4)
3	24	7.0 ± 2.0* (2)	50.7 ±18.0** (2)	3.7 ± 0.6* (3)	5.0 ± 2.0 (4)
3	31	9.9 ± 1.5 (15)	35.0 ± 18.1* (7)	2.0 ± 2.0 (5)	5.3 ± 3.1 (3)
	Control 3	10.9 ± 0.2	7.7 ± 2.0	0.0 ± 0.0	2.7 ± 1.1

*Significantly different ($\alpha = 0.05$) from respective controls.

**Significantly different ($\alpha = 0.01$) from respective controls.

All of the 15 sites except one (site 1) were significantly toxic to at least one of the sea urchin endpoints (Figure 16). Based upon the cumulative evidence from all four cytogenetic/cytologic endpoints in the sea urchin embryos, it appears that sediments from sites 19 (northern South Bay), 21 (China Basin), and 24 (off Islais Creek) generally were most toxic. Embryos exposed to these sediments had significant toxicological results in three of the four endpoints, the results for at least one endpoint were significant at the 0.01 level, and the arithmetic averages often ranked these sites among the most toxic. Sites with moderate toxicity were:

- Site 3 (Richmond Harbor).
- Sites 14 and 15 (both Oakland Inner Harbor).
- Site 42 (Redwood Creek).

Sites with slight toxicity were:

- Sites 2 and 4 (Richmond Harbor).
- Site 13 (off the Alameda NAS).
- Site 23 (Islais Creek).
- Site 31 (off San Bruno).
- Site 41 (Redwood Creek).
- Site 43 (southern South Bay).

Based upon all the data from the cytological/cytogenetic analyses of sea urchin larvae, it appears that site 1 was the least toxic; none of the results were significantly different from controls.

Microtox™ Bioassay of Saline Extracts

A toxic chemical assayed by the Microtox™ test system is characterized by a dose response curve in which increasing doses of toxicity produce decreasing levels of light production by the bioluminescent bacteria. In terms of the observed gamma values, higher toxicity is correlated with higher gammas. In the tests of the saline extracts of the 165 samples from San Francisco Bay, all gamma values were negative. That is, the sediment extracts enhanced, rather than reduced, the light production. Therefore, all saline extracts were characterized as nontoxic (NT) in Appendix B and no further analyses of the data were performed.

Microtox™ Bioassay of Organic Extracts

Data for individual samples listed in Appendix B are summarized as averages for each site in Table 20. Both the average gamma values (the reductions in light production) and the average EC_{50}s (the sediment concentrations at which a 50 percent light reduction in luminescence occurred) are listed for each site. Large gamma values and small EC_{50}s are indicative of toxicity in this test.

The smallest EC_{50}s occurred in tests of sediments from sites 1, 16, 22, 23 and 42 located in San Pablo Bay, San Leandro Bay, off Islais Creek, in Islais Creek, and in South Bay off Redwood Creek, respectively. Out of the 45 sites tested, 26 were determined to be not toxic because the gamma values were very small and, therefore, EC_{50}s could not be calculated. None of the mean results for any of the remaining 19 sites were significantly different from the controls, as determined in chi-square tests ($\alpha = 0.05$).

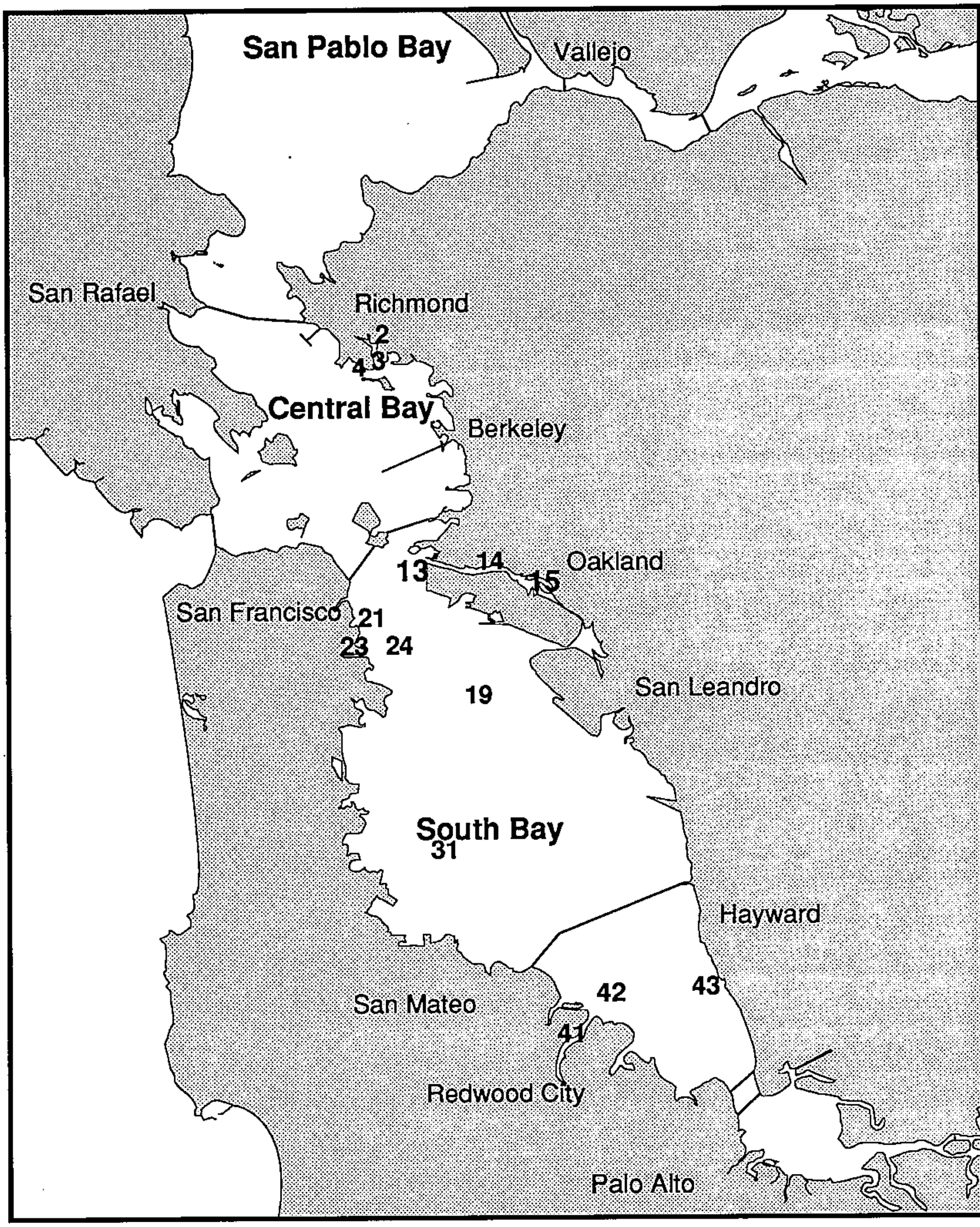

Figure 16. Sampling sites in which significant cytogenetic effects were observed in urchin embryos *(S. purpuratus).*

Table 20. Average (± standard deviation) gamma values and EC_{50} concentrations for 5-minute Microtox™ tests of organic extracts of sediments from 45 sites (three or five samples per site) in San Francisco Bay.

Site Number	Gamma Values	EC_{50} Concentrations
1[a]	4.226 ± 4.087	0.98 ± 0.66
2[a]	0.631 ± 0.301	2.64 ± 1.14
3[a]	0.125 ± 0.062	NT[c]
4[a]	0.050 ± 0.056	NT
5	0.178 ± 0.159	NT
6	0.147 ± 0.100	NT
7	0.072 ± 0.056	NT
8	0.082 ± 0.083	NT
9	0.142 ± 0.202	NT
10	0.043 ± 0.020	NT
11	0.114 ± 0.035	NT
12	0.128 ± 0.005	NT
13[a]	0.670 ± 0.932	3.16 ± 3.07
14[a]	0.184 ± 0.082	2.34 ± 1.55
15[a]	0.410 ± 0.161	2.49 ± 0.86
16	3.760 ± 3.532	0.80 ± 0.32
17	0.341 ± 0.114	5.25 ± 3.21
18	0.105 ± 0.076	NT[c]
19[a]	0.126 ± 0.108	NT
20	0.426 ± 0.129	2.82 ± 0.77
21[a]	0.621 ± 0.402	3.14 ± 1.37
22	8.077 ± 6.671	1.00 ± 1.38
23[a]	13.622 ± 3.547	0.41 ± 0.14
24[a]	0.801 ± 1.071	1.97 ± 0.80
25	0.472 ± 0.087	3.14 ± 1.05
26	0.124 ± 0.036	NT
27	0.385 ± 0.145	4.63 ± 2.39
28	0.168 ± 0.027	NT
29	0.264 ± 0.244	NT
30	0.104 ± 0.006	NT
31[a]	0.125 ± 0.047	NT
32	0.182 ± 0.025	NT
33	0.168 ± 0.057	NT
34	0.176 ± 0.060	NT
35	0.236 ± 0.200	NT
36	0.185 ± 0.004	NT
37	0.210 ± 0.055	NT
38	0.138 ± 0.036	NT
39	0.139 ± 0.085	4.19 ± 2.61
40	0.607 ± 0.372	2.11 ± 0.80
41[a]	1.266 ± 1.534	1.51 ± 0.46
42[a]	9.724 ± 9.080	1.01 ± 0.90

Table 20. Continued.

Site Number	Gamma Values	EC_{50} Concentrations
43[a]	0.050 ± 0.064	NT
44	0.026 ± 0.019	NT
45	8.770 ± 8.950	0.89 ± 0.68
Control 1[a]	0.046 ± 0.009	NT
Control 2[a]	1.682 ± 0.327	1.24 ± 0.22
Control 3[a]	0.182 ± 0.005	>1.65

[a] Averages were calculated based upon five samples collected at the site.

[b] EC_{50} values of 1.65 were used to calculate averages for sites in which one or more of the samples were not toxic at sediment concentrations of 1.65 mg/ml or more.

[c] NT indicates that an EC_{50} could not be calculated in two or more samples because they were not toxic.

SUMMARY

The sites listed in Table 21 were indicated as toxic by one or more of the 10 independent toxicological endpoints. If any one of the different cytological and cytogenetic endpoints in the embryo tests were significantly toxic, an "X" was entered under the umbrella categories of "Urchin Cytological/Cytogenetic" or "Mussel Cytological." Also, if the cytological/cytogenetic results were significant at the 0.01 level or most of the endpoints were significant at the 0.05 level, two Xs were entered in the column. The cytological endpoints were measured in sediments from only 15 of the 45 sites; all 15 of these sites are included in Table 15. None of the results from the Microtox™ tests were significant; a "<1" indicates that the mean EC_{50} for the site was relatively low, *i.e.*, 1.00 or less (an arbitrarily selected value).

Clearly, most of the sites listed in Table 21 were indicated as significantly toxic by the embryo cytological/cytogenetic endpoints. There was remarkably good agreement between the cytogenetic results from both of the larval tests. Only 9 sites out of the 45 were determined to be significantly toxic by the mussel larvae survival or abnormal development endpoints. None were toxic to the Microtox™ test.

If only the mussel larvae survival, abnormal development, and Microtox™ data were used to judge the extent of toxicity among the 45 sites in San Francisco Bay, it would appear that toxicity was relatively low. However, the mussel larvae tests were performed with 50 percent dilutions of the sediment suspensions; and therefore, may have underestimated toxicity in some cases. In the historical data reviewed in chapter 2, considerably fewer sites were identified as toxic in tests performed with the 50 percent dilutions than in those performed with undiluted suspensions. Also, there were considerable differences in the performance of the mussel embryos among the three batches of samples tested. Some of the apparent "toxicity" evident in the samples tested in the second batch may have been attributable to the poorer condition of the larvae used in those tests. In addition, because of the relatively low doses used, the Microtox™ tests may have underestimated toxicity also.

Among the 23 sites listed in Table 21, significant results were observed in the three endpoint categories of (1) mussel larvae survival or abnormal development, (2) urchin cytological/ cytogenetic, and (3) mussel cytological effects in sediments from only two sites:

- Site 13 (off the Alameda NAS)
- Site 15 (Oakland Inner Harbor)

Table 21. Sampling sites and their location in San Francisco Bay that were indicated as toxic in one or more of the toxicity tests.

Site No.	Location	Mussel Survival	Mussel Abnormal Development	Microtox Organic	Urchin Cytological/ Cytogenetic	Mussel Cytological
1	San Pablo Bay	-	X	<1	-	X
2	Richmond Harbor	-	-	-	X	X
3	Richmond Harbor	-	-	-	XX	X
4	Richmond Harbor	-	-	-	X	X
13	off Alameda	-	X	-	X	X
14	Oakland Inner	-	-	-	XX	X
15	Oakland Harbor	-	X	-	XX	X
16	San Leandro Bay	-	X	<1		
19	off San Leandro	-	-	-	XX	X
21	China Basin	-	-	-	XX	XX
22	China Basin	-		<1		
23	Islais Creek	-	-	<1	X	XX
24	Islais Creek	-	-	-	XX	X
30	off San Bruno	X	-	-		
31	off San Bruno	-	-	-	X	X
32	off SFO airport	X	-	-	-	
33	off Coyote Pt.	X	-	-	-	
38	off San Lorenzo	X	-	-	-	
39	off San Lorenzo	X	-	-	-	
41	Redwood Creek	-	-	-	X	X
42	Redwood Creek	-	-	-	XX	X
43	South Bay	-	-	-	X	X
45	Coyote Creek	-	-	<1		

- Indicates that the test was performed, but results were not significantly different from controls. A blank cell indicates that the test was not performed with sediments from that site.

X indicates that the results of the toxicity test were significantly different (more toxic) from respective controls at the 0.05 significance level.

XX under the cytological/cytogenetic categories indicates the results were significant at the 0.01 significance level in at least one endpoint or significant at the 0.05 level in most of the individual endpoints. None of the results of the Microtox™ organic tests were significant; "<1" indicates that the mean EC_{50} was 1.00 or less.

Based upon previous studies, some of the peripheral sites were expected to be highly toxic in these tests. Sites located in or near inner Richmond Harbor, Oakland Outer Harbor, Oakland Inner Harbor, San Leandro Bay, Alameda Naval Base, China Basin, India Basin, Hunters Point, Islais Creek waterway, Coyote Creek, and Redwood Creek were expected to be the most toxic. All of these areas had either been tested and found to be toxic in previous research or had been determined to be relatively highly contaminated. All are peripheral areas very near multiple sources of contaminants. In the present survey, the data collected indicated that samples from Richmond Harbor, Oakland Inner Harbor, San Leandro Bay, China Basin, Islais Creek, Coyote Creek, and Redwood Creek were identified as toxic in one or more of the tests as was expected. Unexpectedly, samples from the Oakland Outer Harbor, Alameda Naval Base, India Basin, and Hunters Point were not toxic.

Sites located in or near outer Richmond Harbor, Point Isabel, Emeryville, Alameda NAS, the South San Francisco/San Bruno/SFO Airport/San Mateo shore of South Bay, off San Lorenzo were expected to be moderately toxic, based upon previous studies. In the present survey, samples collected in or near outer Richmond Harbor (site 4), San Bruno, SFO Airport, and San Lorenzo were toxic in one or more of the tests as was expected. However, unexpectedly, a number of sites that were expected to be moderately toxic were not identified as such in the present tests. These sites included those in or near outer Richmond Harbor (site 5), Point Isabel, Emeryville, Sierra Point near San Bruno, and Coyote Point near San Mateo.

Site 1 located in southwestern San Pablo Bay; sites 7 and 9 located off Berkeley; site 11 northwest of Treasure Island; sites 18, 19, 20 and 22 in northern South Bay; and sites 29, 31, 33, 35, 36, 37, 40, and 44 located in South Bay were expected to be least toxic or not toxic based upon previous studies. Among these sites, sediments from sites 7, 9, 11, 18, 20, 22, 29, 33, 35, 36, 37, 40, and 44 were not toxic in the present tests as was expected. Unexpectedly, sediments from sites 1, 19, and 31 were toxic to one or more endpoints.

In summary, despite the use of relatively diluted samples, toxicity was indicated by all the tests. Tests of development and survival, together, in mussel larvae identified 9 of 45 sites as significantly toxic. Tests with cytological and cytogenetic end-points, in mussel and sea urchin larvae, together, identified 15 of 15 samples as significantly toxic. Tests with bioluminescent bacteria identified five sites as relatively toxic. Toxic sediments were collected in both peripheral harbors and basins of the estuary. The prevalence of toxicity was lower than indicated in historical tests with less diluted samples.

CHAPTER 4

OTHER MEASURES OF BIOLOGICAL EFFECTS ASSOCIATED WITH TOXICANTS.

INTRODUCTION

A number of studies have been performed in San Francisco Bay in which different types of bioeffects have been measured by many investigators. None of these studies were performed with the purpose of characterizing baywide patterns in effects. None, alone, were performed with a sufficiently dense sampling scheme to allow the determination of baywide patterns. All were performed with either fish or water. Since fish are highly mobile and water is very transient, spatial patterns in results cannot be identified with very high spatial resolution. However, the data from the disparate studies are valuable, since they indicate the types and severity of bioeffects associated with toxicants in the estuary.

Since many of these measures of effects have been documented very well by the respective investigators and in previous summary reports (Davis *et al.*, 1990; Long *et al.*, 1988; Phillips, 1987), this chapter will only briefly summarize the information reported on the types of effects that were observed. Documents cited below should be examined for the detailed results of the individual studies.

Mixed-function Oxygenase Induction and Impaired Reproductive Success in Starry Flounder

Studies of organic chemical concentrations in tissues, induction of mixed-function oxygenase (MFO) enzymatic activity in liver tissues, and observations of impaired reproductive success in the starry flounder (*P. stellatus*) were conducted in San Francisco Bay in the 1980s (Spies *et al.*, 1988; Spies and Rice, 1988; Spies *et al.*, 1985). Brief summaries of the large amount of data generated during these studies have been published (Spies *et al.*, 1990; Davis *et al.*, 1990; Long *et al.*, 1988).

Very briefly, these studies identified correlations between elevated concentrations of chlorinated hydrocarbons in the tissues of the fish, the elevated induction of an enzymatic defense mechanism (MFO activity), and reduced reproductive success among females that were spawned. These three responses were most apparent in fish that were collected in the central bay off the Berkeley/Emeryville/Oakland shore. Fish collected in San Pablo Bay generally had lower chemical concentrations, lower MFO activities, and higher reproductive success.

These data and the statistical correlations among them did not establish a cause and effect relationship. However, they collectively provided strong evidence that the fish from the central bay had accumulated chlorinated hydrocarbons, that defense mechanisms known to be responsive to these types of chemicals had been induced, and that fish that had the highest exposures had the lowest reproductive success.

In subsequent analyses of starry flounder, Spies *et al.* (1990) and Long and Buchman (1989; 1990) demonstrated that fish caught in San Francisco Bay near Berkeley, Vallejo, and Oakland generally had higher levels of MFO induction than those collected in the mouth of the Russian River along the northern California coast. Also, these same fish generally had higher ethoxyresorufin-o-deethylase (EROD) activity and cytochrome P-450E enzyme content in liver tissues, again, indicating that their defense mechanisms had been induced following exposure to hydrocarbons.

Enzyme Activity in Staghorn Sculpin Liver Tissue.

A study of seven sites in the San Francisco Bay estuary and one site in Tomales Bay was conducted in 1988 following a large oil spill at Martinez (Spies, 1989b). In that study, staghorn sculpin (*L. armatus*) were collected at each site and the livers were analyzed to determine aryl hydrocarbon hydroxylase (AHH) activity and EROD activity. These two analyses were used as indicators that the fish collected in June and July of 1988 had been exposed to the oil spilled in April 1988. Several sites in the lower Suisun Bay/Carquinez Narrows area were sampled, including two very near the site of the spill. In addition, a site near the oil refineries at Castro Cove in the Richmond area was sampled. Finally, fish were collected at a site in Tomales Bay, an embayment presumed to be pristine.

The mean AHH activities in the fish from all seven San Francisco Bay estuary sites, including those not apparently influenced by the spill, were significantly higher than the mean activity in the fish from Tomales Bay. The arithmetic mean AHH and EROD activities in the fish from the site near Castro Cove that was not influenced by the spill were about 8 times higher than the means for the Tomales Bay fish.

These biomarkers were presumed to remain elevated as long as the fish were exposed to petroleum hydrocarbons, and then diminish as the concentrations gradually decreased (Spies, 1989b). Both of these biomarkers were elevated in fish collected 2 months following the spill at sites influenced by the spilled oil. However, the observation that the samples collected near Castro Cove, some distance from the spill site, had very high enzyme induction levels suggests that these fish had been exposed to persistent sources of hydrocarbons.

Histopathological Disorders Among Bottom-Dwelling Fish

Data from observations of histopathological disorders in fish collected from San Francisco Bay as a part of the NS&T Program have been published by NOAA (1987) and Varanasi *et al.* (1988). Summaries of some of these and other data were prepared by Davis *et al.* (1990) and Long *et al.* (1988). Observations of skin tumors in English sole (*Parophrys vetulus*) reported by several investigators in the 1960s and 1970s were summarized in Long *et al.* (1988).

In a summary of results of their analyses of histopathological disorders in bottom fish sampled during 1984-86 along the Pacific Coast, Varanasi *et al.* (1988) reported that kidney lesions were significantly elevated in starry flounders collected near Hunters Point and at Southhampton Shoals near Richmond. For example, 38 percent of the fish from the Southhampton Shoals site had sclerotic (hardened) lesions of the kidney, as compared to prevalences of about 17 percent at the Hunters Point site and less than 15 percent at the Bodega Bay site. The prevalences of proliferative (growth-related), necrotic (cell death), and sclerotic lesions in kidneys generally were lower in starry flounder collected in San Pablo Bay, Bodega Bay, and Coos Bay, Oregon than in those collected at the Hunters Point and Southhampton Shoals sites. The prevalences of liver lesions generally were low in starry flounder at all sites along the Pacific coast, including the sites sampled in San Francisco Bay. Liver neoplasms in starry flounder collected in 1984 at the San Pablo Bay and Southhampton Shoals sites were reported by NOAA (1987), but not by Varanasi *et al.* (1988).

The prevalences of lesions in white croaker (*Genyonemus lineatus*) collected in 1984-87 in San Francisco Bay also were reported by Varanasi *et al.* (1988). As compared to the white croaker from some of the Southern California sites and the English sole and flathead sole (*Hippoglossoides elassodon*) from Puget Sound sites, the prevalences of kidney lesions in San Francisco Bay fish generally were low (less than 5%). An exception, about

10 percent of the white croaker collected at a site near Oakland had proliferative lesions of the kidney, roughly equivalent to the prevalence of these lesions in English sole from Elliott Bay and flathead sole from Commencement Bay in Puget Sound. Generally, less than 5 percent of the white croaker sampled in San Francisco Bay had any of the individual liver lesions quantified by Varanasi *et al.* (1988). Carrasco *et al.* (1990) reported prevalences of a number of idiopathic liver lesions in white croaker collected as a part of the NS&T Program in 1987. One or more of a lengthy list of liver lesions occurred in 40 percent of the fish collected in the Oakland estuary, as compared to prevalences of 6.7 percent in fish from both Hunters Point and Redwood City, and 0.0 percent in fish from Bodega Bay.

Micronuclei in Peripheral Erythrocytes of Fish

Long and Buchman (1989; 1990) reported up to a 24-fold elevation in the mean incidence of micronuclei in peripheral erythrocytes (blood cells) of starry flounder collected off Berkeley compared to those collected in the mouth of the Russian River. The incidence of this cytological disorder was significantly elevated in fish collected at sites in San Pablo Bay, off Vallejo, and off Berkeley compared to the Russian River fish. This pattern of higher incidences of micronuclei in fish from urban areas than in fish from rural areas also has been reported in a number of other studies performed elsewhere (see Long and Buchman, 1989). However, Carrasco *et al.* (1990) reported a very poor correspondence in micronuclei prevalence and both chemical levels in the tissues and prevalence of idiopathic liver lesions in white croaker sampled at sites ranging from Bodega Bay and San Francisco Bay to Los Angeles Harbor and San Diego Bay. The arithmetic mean prevalences reported for white croaker in San Francisco Bay (Carrasco *et al.*, 1990) were about an order of magnitude lower than the incidences reported for the starry flounder from the bay (Long and Buchman, 1989). Moreover, the prevalence of micronuclei in white croaker was lower in fish from the Oakland estuary, off Redwood City, and off Hunters Point than in those from Bodega Bay (Carrasco *et al.*, 1990).

Scope for Growth in Mussels

Resident mussels (*M. edulis*) collected at five locations in San Francisco Bay and a location in Tomales Bay indicated a strong gradient in Scope for Growth (SFG), a physiological measure of stress in these animals (Martin *et al.*, 1984). SFG has been demonstrated in a number of studies to decrease in animals stressed by environmental factors, including exposure to toxicants. Mussels collected in Redwood Creek had the lowest SFG and this measure gradually increased northward to locations near the San Mateo Bridge, off Hunters Point, off Treasure Island, at Fort Baker and in Tomales Bay. The results from Redwood Creek, San Mateo Bridge, and Hunters Point sites were significantly different (lower) from those from Tomales Bay. The SFG data corresponded to a gradient in a number of chemical contaminants, including several hydrocarbons. The sites with the highest chemical concentrations had the lowest SFG.

Ambient Toxicity of Water

Samples of water from 12 background locations scattered throughout the three basins of the estuary were collected quarterly for a year and tested for toxicity by Anderson *et al.* (1990). Four samples were collected in the Suisun Bay/Grizzly Bay area, four were collected in the Pinole Shoal/Richmond area, and four were collected in the South Bay. A battery of toxicity tests was used, including a test of the fertilization success of either sand dollar or sea urchin sperm cells exposed to the water samples. Among the tests performed, that with the sea urchin or sand dollar sperm cells was most sensitive.

During the first survey (April 1989) all 12 background samples were toxic to the sea urchin sperm cells. During the second survey (August 1989) only the four samples from South Bay were toxic to sand dollar sperm cells. In the third and fourth surveys (December 1989 and April 1990, respectively), some samples from all three areas were toxic to sea urchin sperm cells.

Water samples also were collected once in five marshes and tested for toxicity. Five samples were collected in the San Francisco Bay National Wildlife Refuge adjacent to the southern end of South Bay. Three of the five samples were toxic to sea urchin sperm cells. In July 1989, five samples from the Hayward Marsh were tested: two were toxic to sea urchin sperm cells and three were toxic to silverside minnows. In a second survey (November 1989), seven of eight samples from Hayward Marsh were toxic to sea urchin sperm cells and silverside minnows.

Nine samples from the Mountain View Sanitary District marsh located near Carquinez were tested; three were toxic to the sea urchin sperm cells and one was toxic to silverside minnows. Eight samples from the marshes adjacent to the Sunnyvale Wastewater Treatment Plant were tested; seven were toxic to sea urchin sperm cells. None of the 10 samples from the marshes adjacent to the San Jose/Santa Clara Wastewater Treatment Plant were toxic in any of three different tests.

Anderson *et al.* (1990) concluded that the Hayward Marsh samples were the most toxic and that the toxicity was largely attributable to unionized ammonia; although unionized ammonia levels did not explain all of the toxicity observed. None of the samples from the San Jose/Santa Clara marsh were toxic. The three other marshes had intermediate levels of toxicity.

Mortality and Population Declines Among Striped Bass

Periodic seasonal mortalities of adult striped bass (*M. saxatilis*) and the long-term, gradual decline in the population of this fish in the Sacramento-San Joaquin system have been documented in a large number of reports (*e.g.*, Brown *et al.*, 1987; Bureau of Reclamation, 1990; Urquhart and Knudsen, 1987; Phillips, 1987). The exact cause(s) of the mortalities and population declines have not been conclusively identified. Four factors could be responsible:

- Reductions in striped bass egg production.
- Entrainment losses of young fish via water diversions.
- Food limitations in the food chain that supports the striped bass.
- The effects of toxicants at some stage of the striped bass life cycle.

Most likely, a combination of these factors is responsible for the problems encountered by striped bass. Research is being conducted by many different groups to address all four factors.

Information has been gathered in many studies regarding the possible role of toxicants (aromatic hydrocarbons, herbicides, and pesticides) in causing these problems in striped bass (Whipple, 1984; Jung *et al.*, 1984; Sakanari *et al.*, 1984; Cashman *et al.*, 1989). The possible relationships between monocyclic aromatic hydrocarbons and diminished reproductive success in striped bass were explored by Whipple (1984), Jung *et al.* (1984), and Sakanari *et al.* (1984). Data from the chemical analyses of plasma and histological examinations of livers of moribund fish examined by Brown *et al.* (1987) indicated that these animals had a number of liver disfunctions. The cause of the liver disfunctions was not determined, but could have been attributed, at least in part, to exposure to toxicants in the Sacramento-San Joaquin system. Cashman *et al.* (1989) demonstrated the enzymatic oxidation of the herbicide eptam in hepatic microsomes of striped bass. They concluded that the oxidation of eptam and other similar herbicides may represent a bioactivation route that explains the toxicity of thiocarbamate herbicides to freshwater fish.

It is not possible at this time to attribute the cause of mortalities and population declines of striped bass to only toxicants. Also, since these fish migrate to and from only the Sacramento-San Joaquin Delta, these measures of biological effects cannot be performed with fish caught throughout the San Francisco Bay estuary. Therefore, they cannot be used as biomarkers in a bay-wide evaluation. However, there is sufficient compelling evidence from a number of investigations to warrant concern that toxicants at least contribute to the observed effects in this species.

CHAPTER 5
CONCLUSIONS

MAGNITUDE OF EFFECTS

Potentially toxic chemicals occur in the San Francisco Bay estuary at concentrations that equal or exceed those levels commonly associated with toxicity or other adverse biological effects. The potential for toxicity is frequently highest in the harbors, ports, and waterways around the perimeter of the estuary and lowest in the open basins. The concentrations of some toxicants often associated with anthropogenic sources were highly correlated with toxicity in sediments. Many different types of biological effects associated with exposure to toxic chemicals have been observed in biota in the San Francisco Bay estuary. They include a number of indicators of toxic effects in several species of resident fish, stress in mussels, toxicity in water, and toxicity in sediments. The measures of toxic effects observed thus far are:

- significantly elevated (relative to controls) incidences of abnormal development in bivalve and urchin larvae exposed to sediments collected within the estuary;
- significantly elevated (relative to controls) mortality of amphipods exposed to sediments collected from locations throughout the estuary;
- up to 100 percent mortality in amphipods or 100 percent abnormal development in bivalve larvae exposed to sediments from many areas within the estuary;
- significantly elevated (relative to controls) incidences of cytogenetic effects in mussel and urchin larvae exposed to sediments collected within the estuary;
- relatively high toxicity to bioluminescent bacteria exposed to sediment extracts;
- significantly higher hepatic enzymatic activity and lowered reproductive success in bottom-dwelling fish (starry flounder) associated with elevated concentrations of organic compounds in the tissues as compared to fish caught outside the estuary and to fish with lower contaminant concentrations;
- significantly elevated hepatic enzymatic activity in staghorn sculpin caught at seven sites in the estuary as compared to fish collected outside the estuary;
- relatively high incidences of kidney lesions in starry flounder collected at sites in the estuary as compared to fish caught elsewhere along the Pacific coast;
- relatively high incidences of liver lesions in white croaker caught at sites within the estuary as compared to fish collected elsewhere along the Pacific coast;
- significantly elevated incidences of micronuclei in blood cells of starry flounder collected within the estuary as compared to fish caught along the Pacific Coast;
- significantly elevated toxicity in invertebrates exposed to water samples collected at locations around the perimeter of the estuary;
- periodic seasonal mortalities of adult striped bass and a gradual decline in population size in the Sacramento-San Joaquin system; and
- significantly reduced scope for growth in resident mussels collected in South Bay relative to mussels collected nearer Golden Gate and outside the estuary.

Collectively, all of these observations strongly suggest that adverse biological effects occur that are at least partly attributable to toxicants in the estuary. They are indicative of toxicant-related effects at the sub-cellular, cellular, histological, organ, and whole organism levels of biological organization. They are indicative of a range of biological effects, including death; prevalence of histopathological disorders; impaired reproductive success; abnormal development of juvenile animals; reduced metabolic processes; induced defense mechanisms; and chromosomal damage.

SPATIAL EXTENT OF EFFECTS

It is not possible at this time, based upon the bioeffects data available, to delineate precisely and exclusively the area or areas in San Francisco Bay where toxicant-related bioeffects occur. Several weaknesses in the available data lead to this conclusion. Some areas have not been sampled and tested for biological effects. A delineation of the spatial extent of effects associated with toxicants using the currently available information could lead to the wrongful exclusion of areas for which there are no empirical data. The density of sampling in most areas has been insufficient to accurately delineate the boundaries of the toxic areas versus the adjoining nontoxic areas. Contradictory data, some indicating toxic effects and others indicating none, have been generated for some areas in different studies or in different tests performed in the same study. Some of this variability and apparent contradiction can be attributed to small-scale patchiness and/or the temporal variability in the distribution and concentration of toxicants. Also, the types of measures have differed in sensitivity and seasonal variation. Measures of bioeffects in fish and water cannot be used to define spatial extent with high resolution due to their mobility. Effects quantified in mobile animals such as fish cannot be attributed unequivocally to toxicants at the site of collection. Some of the biomarkers for which data have been generated also could be triggered by factors other than just the toxic chemicals that have been quantified.

It would be easy to simply draw circles around the most notoriously polluted peripheral harbors and waterways of the San Francisco Bay estuary and label them as the most toxic areas. Compelling evidence from chemical analyses and toxicity tests of sediments collected there would suggest that environmental conditions in many of these areas are clearly less than pristine. However, the most intense sampling has occurred in these areas; and, therefore, the data availability is biased toward the identification of only these areas as the most toxic areas. The considerably less abundant data from the open basins of the estuary have occasionally indicated that toxicant-associated bioeffects occur in those areas, also. Therefore, toxicant-associated effects are not restricted to only the peripheral areas.

Because of the uneven amount of data available from the many regions of the estuary and other problems mentioned above, the task of summing up the individual evidence regarding the spatial extent of effects is difficult. The approach taken below involved an itemization of the evidence that has been gathered thus far in which toxicant-associated bioeffects have been observed or quantified in each major area of the estuary. This approach is necessarily subjective and susceptible to the biases inherent in a subjective approach. The uneven levels of effort in research performed in each area thus far are reflected in the lengths of the lists of the data available. Also, the sizes of the areas differ considerably, and variability in results within the larger areas is to be expected. Nevertheless, based upon the available data, some areas clearly are worse than others.

Sacramento-San Joaquin Delta/Suisun Bay/Carquinez Strait

- observations of mortality, histological disorders, liver disfunction and diminished populations of migratory striped bass;
- moderate incidences of ambient water toxicity in marshes near Martinez;
- some background water samples very toxic to sea urchin sperm cells;
- sediment highly toxic to bivalve embryos in the Suisun Slough channel in historical tests;
- moderately elevated prevalence of erythrocyte micronuclei, hepatic MFO activity, hepatic EROD content, and cytochrome P-450 activity in starry flounder collected near Vallejo.

Mare Island Strait

- elevated concentrations of silver, chromium, and lead in sediments;
- sediments highly toxic to bivalve larvae in historical tests.

San Pablo Bay

- elevated concentrations of chromium, lead, and mercury in sediments;
- sediments from southwestern San Pablo Bay slightly toxic to not toxic to amphipods in historical tests;
- sediments from southwestern San Pablo Bay slightly toxic to not toxic to bivalve larvae in historical tests;
- sediments from one site in southwestern San Pablo Bay not toxic to bivalve larvae survival, but toxic to abnormal larval development in 1990 survey;
- sediments from one site in southwestern San Pablo Bay toxic to bivalve cytogenetic endpoints in 1990 survey;
- sediments from one site in southwestern San Pablo Bay not toxic to sea urchin cytogenetic endpoints in 1990 survey;
- sediments from one site in southwestern San Pablo Bay relatively toxic to bacterial bioluminescence in 1990 survey;
- relatively low hepatic EROD activity and cytochrome P-450 content, low to moderate hepatic MFO activity, moderate erythrocyte micronucei prevalences in starry flounder;
- relatively high reproductive success and low tissue contaminant levels in starry flounder from southwestern San Pablo Bay;
- no liver lesions in starry flounder from eastern San Pablo Bay, 1984-86.

Castro Cove

- relatively high liver MFO and EROD activities in staghorn sculpin;
- sediments highly toxic to amphipods in historical tests;
- sediments moderately toxic to bivalve larvae in historical tests.

Richmond Harbor

- elevated concentrations of DDT, chromium, lead, and mercury in sediments;
- sediments moderately toxic to amphipods in historical tests;
- sediments moderately to highly toxic to bivalve larvae in historical tests;
- sediments not toxic to bivalve larvae in 1990 survey;
- sediments moderately toxic to bivalve larvae cytogenetic endpoints in 1990 survey;
- sediments moderately to highly toxic to urchin larvae cytogenetic endpoints in 1990 survey;
- sediments not toxic to bacteria bioluminescence in 1990 survey.

Eastern portion of Central Bay

- elevated concentrations of chromium, lead, and mercury in sediments;
- relatively low hepatic EROD activity, moderate hepatic cytochrome P-450 activity, and high erythrocyte micronuclei prevalences in starry flounder off Berkeley, 1986;

- relatively high hepatic MFO activity, low reproductive success, and high tissue chemical levels in starry flounder off Berkeley, 1982-85;
- very high prevalences of kidney lesions in starry flounder from Southhampton Shoals, 1984-86;
- low prevalences of liver lesions in starry flounder from Southhampton Shoals, 1984-86;
- some background water samples very toxic to sea urchin sperm cells;
- sediments collected near Pt. Molate highly toxic to bivalve larvae in historical tests;
- sediments collected off Emeryville moderately toxic to amphipods in historical tests;
- sediments collected off Emeryville slightly to not toxic to bivalve larvae in historical tests;
- sediments collected off Berkeley/Emeryville not toxic to bivalve larvae in 1990 survey;
- sediments collected off Berkeley/Emeryville not toxic to bacterial bioluminescence in 1990 survey.

Oakland Inner-Middle-Outer Harbors/San Leandro Bay

- elevated concentrations of chromium, lead, silver, and mercury in sediments;
- sediments moderately to very toxic to amphipods in historical tests;
- sediments slightly to moderately toxic to bivalve larvae in historical tests;
- most sediments slightly toxic to sea urchin larvae in historical tests;
- some sediments very toxic to bivalve abnormal development in 1990 survey;
- some sediments very toxic to bivalve cytogenetic endpoints in 1990 survey;
- some sediments toxic to urchin larvae cytogenetic endpoints in 1990 survey;
- sediments from two sites in Inner Harbor not toxic and those from one site in San Leandro Bay relatively toxic to bacterial bioluminescence in 1990 survey;
- relatively high prevalence of liver disorders in white croaker;
- high hepatic EROD activity and hepatic cytochrome P-450 activity, but relatively low erythrocyte micronuclei prevalences in starry flounder;
- moderate prevalences of erythrocyte micronuclei in white croaker.

Northern Part of South Bay (Oakland Bay Bridge to San Mateo Bridge)

- no liver lesions in white croaker off Alameda NAS, 1984-86;
- moderate prevalences of kidney lesions in white croaker off Alameda NAS, 1984-86;
- relatively high scope for growth in resident mussels from Treasure Island;
- low prevalences of liver and kidney lesions in white croaker and liver lesions in starry flounder off Hunters Point, 1984-86;
- very high prevalences of kidney lesions in starry flounder off Hunters Point, 1984-86;
- significantly depressed scope for growth in resident mussels from Hunters Point;
- sediments throught the area moderately toxic to amphipods in historical tests;
- some background ambient water samples toxic to sea urchin sperm cells;

- 5 samples out of 20 toxic to bivalve larvae survival-collected between San Leandro and San Mateo/SFO airport, in 1990 survey;
- several sediment samples very toxic to bivalve larvae cytogenetic endpoints in 1990 survey;
- some sediment samples very toxic to sea urchin larvae cytogenetic endpoints in 1990 survey;
- sediment samples from most sites not toxic, those collected near Islais Creek and in China Basin relatively toxic to bacterial bioluminescence in 1990 survey.

Central Part of South Bay (San Mateo Bridge to Dumbarton Bridge)

- ambient water samples from Hayward Marsh very toxic to sea urchin sperm cells;
- some sediment samples collected off Hayward/San Lorenzo highly toxic to amphipods in historical tests;
- sediments not toxic to bivalve larvae in 1990 survey;
- sediment samples from two sites toxic to sea urchin cytogenetic endpoints in 1990 survey;
- sediment samples from two sites toxic to mussel larvae cytogenetic endpoints in 1990 survey;
- sediments not toxic to bacterial bioluminescence in 1990 survey;
- significantly depressed scope for growth in resident mussels from San Mateo Bridge.

Southern Part of South Bay (south of Dumbarton Bridge)

- ambient water samples frequently toxic to sea urchin sperm cells;
- ambient water samples collected near Sunnyvale frequently toxic, but those collected near San Jose/Santa Clara not toxic, to sea urchin sperm cells;
- sediments slightly toxic to amphipods (except, one sample extremely toxic to *E. estuarius*) in historical tests;
- sediments not toxic to bivalve larvae in historical tests;
- sediments from one site not toxic to bivalve larvae in 1990 survey;
- sediments from one site not toxic, those from another site relatively toxic to bacterial bioluminescence in 1990 survey.

Redwood Creek

- elevated concentrations of chromium and lead in sediments;
- •sediments toxic to bivalve larvae cytogenetic endpoints in 1990 survey;
- sediments toxic to sea urchin larvae cytogenetic endpoints in 1990 survey;
- sediments not toxic to sea urchin larvae in 1990 survey;
- sediments very toxic to bivalve larvae in historical tests;
- low prevalence of idiopathic liver lesions in white croaker sampled in 1987;
- significantly depressed scope for growth in resident mussels.

Guadalupe Slough

- elevated concentrations of mercury in sediments;
- sediments not toxic to amphipods in historical tests;

- sediments very toxic to bivalve larvae in historical tests.

Port of San Francisco (Islais Creek to Fishermen's Wharf)

- elevated concentrations of silver, chromium, lead, mercury, PCB, and PAHs in sediments;
- sediments very toxic to amphipods in historical tests;
- sediments moderately toxic to bivalve larvae in historical tests;
- sediments not toxic to bivalve larvae in 1990 survey;
- sediments toxic to bivalve larvae cytogenetic endpoints in 1990 survey;
- sediments toxic to sea urchin larvae cytogenetic endpoints in 1990 survey;
- sediments not toxic to bacterial bioluminescence in 1990 survey.

Based upon this cumulative evidence, some areas were identified that have been studied extensively in multiple surveys, in which different types of measures of effects have been performed, where chemical concentrations in sediments were elevated relative to toxic effects thresholds, and in which most of the measures of effects were elevated above conditions in other areas in the bay. These areas include:

- Sacramento-San Joaquin Delta/Suisun Bay/Carquinez Strait area.
- Castro Cove near Richmond.
- Oakland Inner-Middle-Outer Harbors/San Leandro Bay area.
- Parts of South Bay between the Oakland Bay Bridge and the San Mateo Bridge, particularly in the vicinity of the Port of San Francisco, Hunters Point, and Islais Creek.
- Guadalupe Slough, adjacent to the southern portion of South Bay south of the Dumbarton Bridge.

Areas in which moderately toxic conditions occurred or some of the measures of effects were elevated relative to other areas included: Richmond Harbor, Central Bay off the Berkeley/Emeryville shore, Redwood Creek, and parts of South Bay between the San Mateo Bridge and the Dumbarton Bridge. Most of the data suggest that biological effects were least frequent or least severe in San Pablo Bay; however, some data from the 1990 synoptic survey indicated toxicity. There were very little or no data available with which to evaluate Richardson Bay, most of San Pablo Bay, the Golden Gate area, and the western portion of Central Bay.

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APPENDIX A

SEDIMENT TOXICITY DATA COMPILED FROM 60 INDIVIDUAL STUDIES PERFORMED IN SAN FRANCISCO BAY

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Bioeffects Evaluation(1)										
upper Oakland Estuary	OA-1	2/23/87	2 cm grab	*Rhepoxynius*	amphipod	Y	69		P	OAKIN
upper Oakland Estuary	OA-2	2/23/87	2 cm grab	*Rhepoxynius*	amphipod	Y	61		P	OAKIN
upper Oakland Estuary	OA-3	2/23/87	2 cm grab	*Rhepoxynius*	amphipod	Y	56		P	OAKIN
upper Oakland Estuary	OA-1	2/23/87	2 cm grab	PSP	bivalve	Y	25.8		P	OAKIN
upper Oakland Estuary	OA-2	2/23/87	2 cm grab	PSP	bivalve	Y	20.5		P	OAKIN
upper Oakland Estuary	OA-3	2/23/87	2 cm grab	PSP	bivalve	Y	26.5		P	OAKIN
Bioeffects Evaluation(1)										
off Emeryville	YB-1	2/23/87	2 cm grab	*Rhepoxynius*	amphipod	Y	26		B	CEN
off Emeryville	YB-2	2/23/87	2 cm grab	*Rhepoxynius*	amphipod	Y	33		B	CEN
off Emeryville	YB-3	2/23/87	2 cm grab	*Rhepoxynius*	amphipod	Y	41		B	CEN
off Emeryville	YB-1	2/23/87	2 cm grab	PSP	bivalve	Y	15.3		B	CEN
off Emeryville	YB-2	2/23/87	2 cm grab	PSP	bivalve	Y	14.8		B	CEN
off Emeryville	YB-3	2/23/87	2 cm grab	PSP	bivalve	Y	11.4		B	CEN
Bioeffects Evaluation(1)										
off Vallejo, Semple Point	VA-1	2/20/87	2 cm grab	*Rhepoxynius*	amphipod	Y	69		B	SPB
off Vallejo, Semple Point	VA-2	2/20/87	2 cm grab	*Rhepoxynius*	amphipod	N	10		B	SPB
off Vallejo, Semple Point	VA-3	2/20/87	2 cm grab	*Rhepoxynius*	amphipod	N	16		B	SPB
off Vallejo, Semple Point	VA-1	2/20/87	2 cm grab	PSP	bivalve	Y	13.3		B	SPB
off Vallejo, Semple Point	VA-2	2/20/87	2 cm grab	PSP	bivalve	N	6.5		B	SPB
off Vallejo, Semple Point	VA-3	2/20/87	2 cm grab	PSP	bivalve	Y	9.1		B	SPB
Bioeffects Evaluation(1)										
San Pablo Bay	SP-1	2/22/87	2 cm grab	*Rhepoxynius*	amphipod	Y	9		B	SPB
San Pablo Bay	SP-2	2/22/87	2 cm grab	*Rhepoxynius*	amphipod	Y	54		B	SPB
San Pablo Bay	SP-3	2/22/87	2 cm grab	*Rhepoxynius*	amphipod	Y	17		B	SPB
San Pablo Bay	SP-1	2/22/87	2 cm grab	PSP	bivalve	Y	7.4		B	SPB
San Pablo Bay	SP-2	2/22/87	2 cm grab	PSP	bivalve	Y	14		B	SPB
San Pablo Bay	SP-3	2/22/87	2 cm grab	PSP	bivalve	Y	7.9		B	SPB
Bioeffects Evaluation(1)										
Tomales Bay	TB-1	2/24/87	2 cm grab	*Rhepoxynius*	amphipod	Y	72		TB	TB
Tomales Bay	TB-2	2/24/87	2 cm grab	*Rhepoxynius*	amphipod	Y	45		TB	TB
Tomales Bay	TB-3	2/24/87	2 cm grab	*Rhepoxynius*	amphipod	Y	70		TB	TB
	Ave.									
Tomales Bay	TB-1	2/24/87	2 cm grab	PSP	bivalve	Y	19		TB	TB
Tomales Bay	TB-2	2/24/87	2 cm grab	PSP	bivalve	Y	15.3		TB	TB
Tomales Bay	TB-3	2/24/87	2 cm grab	PSP	bivalve	Y	16		TB	TB

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Hunters Point Navy EIS (2)										
Treasure Island	Ti - 1hp	10/5/86	Composited core	*Rhepoxynius*	amphipod	Y	69		P	TI
Treasure Island	Ti - 2hp	8/20/86	Composited core	*Rhepoxynius*	amphipod	Y	27		P	TI
Treasure Island	Ti - 3hp	8/20/86	Composited core	*Rhepoxynius*	amphipod	Y	34		P	TI
Treasure Island	Ti - 4hp	10/5/86	Composited core	*Rhepoxynius*	amphipod	Y	70		P	TI
Treasure Island	Ti - 6hp	10/5/86	Composited core	*Rhepoxynius*	amphipod	Y	52		P	TI
Treasure Island	Ti - 7hp	10/5/86	Composited core	*Rhepoxynius*	amphipod	Y	38		P	TI
Treasure Island	Ti - 1hp	10/5/86	Composited core	100%	bivalve	Y	22.7		P	TI
Treasure Island	Ti - 2hp	8/20/86	Composited core	100%	bivalve	Y	46		P	TI
Treasure Island	Ti - 3hp	8/20/86	Composited core	100%	bivalve	Y	75		P	TI
Treasure Island	Ti - 4hp	10/5/86	Composited core	100%	bivalve	Y	27		P	TI
Treasure Island	Ti - 6hp	10/5/86	Composited core	100%	bivalve	Y	13		P	TI
Treasure Island	Ti - 7hp	10/5/86	Composited core	100%	bivalve	Y	13		P	TI
Hunters Point Navy EIS (2)										
Alameda Navy Base	AL - 1hp	10/5/86	Composited core	*Rhepoxynius*	amphipod	Y	31		P	ANB
Alameda Navy Base	AL - 2hp	10/5/86	Composited core	*Rhepoxynius*	amphipod	Y	36		P	ANB
Alameda Navy Base	AL - 1hp	10/5/86	Composited core	100%	bivalve	Y	23		P	ANB
Alameda Navy Base	AL - 2hp	10/5/86	Composited core	100%	bivalve	Y	19		P	ANB
Hunters Point Navy EIS (2)										
Hunters Point	HP - 1hp	8/20/86	Composited core	*Rhepoxynius*	amphipod	Y	31		P	HUN
Hunters Point	HP - 2hp	8/20/86	Composited core	*Rhepoxynius*	amphipod	Y	35		P	HUN
Hunters Point	HP - 4hp	8/20/86	Composited core	*Rhepoxynius*	amphipod	Y	20		P	HUN
Hunters Point	HP - 1hp	8/20/86	Composited core	100%	bivalve	Y	67		P	HUN
Hunters Point	HP - 2hp	8/20/86	Composited core	100%	bivalve	Y	92.7		P	HUN
Hunters Point	HP - 4hp	8/20/86	Composited core	100%	bivalve	Y	64		P	HUN
Triad Study (3)										
San Pablo Bay	SP 02	7/7/85	2 cm grab	*Rhepoxynius*	amphipod	N	9		B	SPB
San Pablo Bay	SP 05	7/7/85	2 cm grab	*Rhepoxynius*	amphipod	N	4		B	SPB
San Pablo Bay	SP 09	7/7/85	2 cm grab	*Rhepoxynius*	amphipod	N	24		B	SPB
San Pablo Bay	SP 02	7/7/85	2 cm grab	PSP	bivalve	N	13.4		B	SPB
San Pablo Bay	SP 05	7/7/85	2 cm grab	PSP	bivalve	N	7.7		B	SPB
San Pablo Bay	SP 09	7/7/85	2 cm grab	PSP	bivalve	N	15.3		B	SPB
Triad Study (3)										
off Alameda NAS	OA 02	7/8/85	2 cm grab	*Rhepoxynius*	amphipod	N	9		B	SOBAY-N
off Alameda NAS	OA 05	7/8/85	2 cm grab	*Rhepoxynius*	amphipod	N	13		B	SOBAY-N
off Alameda NAS	OA 09	7/8/85	2 cm grab	*Rhepoxynius*	amphipod	N	13		B	SOBAY-N
off Alameda NAS	OA 02	7/8/85	2 cm grab	PSP	bivalve	N	14.5		B	SOBAY-N
off Alameda NAS	OA 05	7/8/85	2 cm grab	PSP	bivalve	Y	24.7		B	SOBAY-N
off Alameda NAS	OA 09	7/8/85	2 cm grab	PSP	bivalve	Y	18.7		B	SOBAY-N

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Triad Study (3)										
Islais Creek	IS 02	7/9/85	2 cm grab	*Rhepoxynius*	amphipod	Y	95		P	ISLAIS
Islais Creek	IS 05	7/9/85	2 cm grab	*Rhepoxynius*	amphipod	N	24		P	ISLAIS
Islais Creek	IS 09	7/9/85	2 cm grab	*Rhepoxynius*	amphipod	Y	37		P	ISLAIS
Islais Creek	IS 02	7/9/85	2 cm grab	PSP	bivalve	Y	67.7		P	ISLAIS
Islais Creek	IS 05	7/9/85	2 cm grab	PSP	bivalve	Y	65.9		P	ISLAIS
Islais Creek	IS 09	7/9/85	2 cm grab	PSP	bivalve	Y	31.9		P	ISLAIS
LOWER OAKLAND										
Inner Harbor (4)										
entrance Inner Harbor	OK1-1	3/23/88	Composited core	*Rhepoxynius*	amphipod	N	16.2		P	OAKIN
entrance Inner Harbor	OK1-2	3/23/88	Composited core	*Rhepoxynius*	amphipod	N	22.5		P	OAKIN
lower Inner Harbor reach	OK1-3	3/23/88	Composited core	*Rhepoxynius*	amphipod	Y	30		P	OAKIN
lower Inner Harbor reach	OK2-1	3/23/88	Composited core	*Rhepoxynius*	amphipod	N	26		P	OAKIN
mid-Inner Harbor	OK2-2	3/21/88	Composited core	*Rhepoxynius*	amphipod	N	26		P	OAKIN
mid-Inner Harbor	OK3-1	3/21/88	Composited core	*Rhepoxynius*	amphipod	Y	35		P	OAKIN
mid-Inner Harbor	OK3-2	3/21/88	Composited core	*Rhepoxynius*	amphipod	Y	38		P	OAKIN
mid-Inner Harbor	CH-1	3/22/88	Composited core	*Rhepoxynius*	amphipod	N	21		P	OAKIN
mid-Inner Harbor	CH-2	3/22/88	Composited core	*Rhepoxynius*	amphipod	Y	31		P	OAKIN
Schnitzer steel mid Harbor	SN-1	3/21/88	Composited core	*Rhepoxynius*	amphipod	N	23		P	OAKIN
Schnitzer steel mid Harbor	SN-2-Upp	3/22/88	Composited core	*Rhepoxynius*	amphipod	Y	30		P	OAKIN
Schnitzer steel mid Harbor	SN-2-Low	3/22/88	Composited core	*Rhepoxynius*	amphipod	Y	24		P	OAKIN
Schnitzer steel mid Harbor	SN-3-Upp	3/21/88	Composited core	*Rhepoxynius*	amphipod	N	24		P	OAKIN
Schnitzer steel mid Harbor	SN-3-Low	3/21/88	Composited core	*Rhepoxynius*	amphipod	Y	36		P	OAKIN
Todd Shipyard mid harbor	TD-1-Upp	3/21/88	Composited core	*Rhepoxynius*	amphipod	N	23		P	OAKIN
Todd Shipyard mid harbor	TD-1-Low	3/21/88	Composited core	*Rhepoxynius*	amphipod	N	22		P	OAKIN
Todd Shipyard mid harbor	TD-2-Upp	3/22/88	Composited core	*Rhepoxynius*	amphipod	Y	30		P	OAKIN
Todd Shipyard mid harbor	TD-2-Low	3/22/88	Composited core	*Rhepoxynius*	amphipod	Y	32		P	OAKIN
Schnitzer steel mid harbor	SN-2-U	3/22/88	Composited core	100%	bivalve	Y	37.5		P	OAKIN
Schnitzer steel mid harbor	SN-2-L	3/22/88	Composited core	100%	bivalve	N	92.6		P	OAKIN
Todd Shipyard mid harbor	TD-2-U	3/22/88	Composited core	100%	bivalve	Y	94		P	OAKIN
Todd Shipyard mid harbor	TD-2-L	3/22/88	Composited core	100%	bivalve	Y	94.3		P	OAKIN
mid Channel	CH-C	3/22/88	Composited core	100%	bivalve	N	4		P	OAKIN
Schnitzer steel mid harbor	SN-2-U	3/22/88	Composited core	50%	bivalve		4.4		P	OAKIN
Schnitzer steel mid harbor	SN-2-L	3/22/88	Composited core	50%	bivalve		11.9		P	OAKIN
Todd Shipyard mid harbor	TD-2-U	3/22/88	Composited core	50%	bivalve		5.1		P	OAKIN
Todd Shipyard mid harbor	TD-2-L	3/22/88	Composited core	50%	bivalve		23.8		P	OAKIN
mid Channel	CH-C	3/22/88	Composited core	50%	bivalve		11.7		P	OAKIN
Redwood City Harbor(5)										
South Bay	Sect. 1	2/7/89	Composited core	100%	bivalve	Y	89.9		B	SOBAY-S
Harbor mouth	Sect. 2	2/7/89	Composited core	100%	bivalve	Y	99.5		P	RED
Alcatraz Dump site	B & D	2/10/89	Composited core	100%	bivalve	Y	99.1		ALC	ALC

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
South Bay	Sect. 1	2/7/89	Composited core	50%	bivalve	N	47.2		B	SOBAY-S
Harbor mouth	Sect. 2	2/7/89	Composited core	50%	bivalve	N	32.2		P	RED
Alcatraz Dump site	B & D	2/10/89	Composited core	50%	bivalve	N	46.4		ALC	ALC
Redwood City Harbor (19)										
City Harbor	Sect. 6	10/2/89	Composited core	100%	bivalve	Y	66.3		P	RED
Alcatraz Dump site	A,B,C,D	10/2/89	Composited core	100%	bivalve	Y	99.7		ALC	ALC
City Harbor	Sect. 6	10/2/89	Composited core	50%	bivalve	N	1.4		P	RED
Alcatraz Dump site	A,B,C,D	10/2/89	Composited core	50%	bivalve	N	79.5		ALC	ALC
Point Molate Fuel Pier(6)										
Behind pier	A	5/17/88	Composited core	100%	bivalve	Y	100		P	PTMO
West of pier	B	5/18/88	Composited core	100%	bivalve	Y	100		P	PTMO
Behind pier	A	5/17/88	Composited core	50%	bivalve	na	21		P	PTMO
West of pier	B	5/18/88	Composited core	50%	bivalve	na	14.7		P	PTMO
Alcatraz disposal site	Ref	5/18/88	Composited core	100%	bivalve	N	0		ALC	ALC
Oakland Harbor Improvement(7)										
Oakland Inner 1-lower	1	Dec-86	Composited core	100%	bivalve	Y	13.7		P	OAKIN
Oakland Inner 2-mid	2	Dec-86	Composited core	100%	bivalve	N	1		P	OAKIN
Oakland Inner 3-mid	3	Dec-86	Composited core	100%	bivalve	N	16.7		P	OAKIN
Oakland Outer 1-compos.	1	Dec-86	Composited core	100%	bivalve	N	2.7		P	OAKOUT
Oakland Outer 2-compos.	2	Dec-86	Composited core	100%	bivalve	Y	5		P	OAKOUT
Oakland Inner 1-lower	1	Dec-86	Composited core	50%	bivalve	N	9.7		P	OAKIN
Oakland Inner 2-mid	2	Dec-86	Composited core	50%	bivalve	N	0.3		P	OAKIN
Oakland Inner 3-mid	3	Dec-86	Composited core	50%	bivalve	N	14		P	OAKIN
Oakland Outer 1-compos	1	Dec-86	Composited core	50%	bivalve	N	3		P	OAKOUT
Oakland Outer 2-compos	2	Dec-86	Composited core	50%	bivalve	N	2.3		P	OAKOUT
Oakland Inner 1-lower	1	Dec-86	Composited core	*Rhepoxynius*	amphipod	Y	44		P	OAKIN
Oakland Inner 2-mid	2	Dec-86	Composited core	*Rhepoxynius*	amphipod	Y	70		P	OAKIN
Oakland Inner 3-mid	3	Dec-86	Composited core	*Rhepoxynius*	amphipod	Y	74		P	OAKIN
Oakland Outer 1-compos	1	Dec-86	Composited core	*Rhepoxynius*	amphipod	Y	79		P	OAKOUT
Oakland Outer 2-compos	2	Dec-86	Composited core	*Rhepoxynius*	amphipod	Y	72		P	OAKOUT
Alcatraz Disposal site	1	Dec-86	Composited core	*Rhepoxynius*	amphipod	N	2		ALC	ALC

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Pinole Shoal Channel, mid-San Pablo Bay (8)										
Section 3	3	Dec-88	Composited core	100%	bivalve	Y	15.1		B	SPB
Section 4	4	Dec-88	Composited core	100%	bivalve	Y	100		B	SPB
San Pablo Disposal site	Ref.	Dec-88	Composited core	100%	bivalve	N	6.9		SPDS	SPDS
Section 3	3	Dec-88	Composited core	50%	bivalve	N	5.3		B	SPB
Section 4	4	Dec-88	Composited core	50%	bivalve	N	47.2		B	SPB
San Pablo Disposal site	Ref.	Dec-88	Composited core	50%	bivalve	N	7.5		SPDS	SPDS
Mare Island Strait (9)										
Mid-strait	Sect. 4	OCT. 88	Composited core	100%	bivalve	Y	42.4		P	MARE
Upper strait	Sect. 6	OCT. 88	Composited core	100%	bivalve	Y	22.4		P	MARE
Carquinez disposal site	Ref.	OCT. 88	Composited core	100%	bivalve	Y	98.7		CAR	CAR
Mid-strait	Sect. 4	OCT. 88	Composited core	50%	bivalve	N	6.8		P	MARE
Upper strait	Sect. 6	OCT. 88	Composited core	50%	bivalve	N	11.6		P	MARE
Carquinez disposal site	Ref.	OCT. 88	Composited core	50%	bivalve	N	7.6		CAR	CAR
Port of San Francisco (10)										
Pier 35, north San Francisco	2	4/22/88	Compstd 1' core	100%	bivalve	Y	100		P	PORTSF
Pier 27, north San Francisco	5	4/22/88	Compstd 1' core	100%	bivalve	Y	100		P	PORTSF
Pier 48, China Basin	6	4/22/88	Compstd 1' core	100%	bivalve	Y	100		P	PORTSF
Pier 80, east of pier	9	4/22/88	Compstd 1' core	100%	bivalve	N	0.7		P	PORTSF
Pier 80, Islais Creek	10	4/22/88	Compstd 1' core	100%	bivalve	Y	51		P	ISLAIS
Pier 45, no. San Francisco	12	4/22/88	Compstd 1' core	100%	bivalve	Y	35		P	PORTSF
Alcatraz disposal site	Ref. 13	4/22/88	Compstd core	100%	bivalve	N	0.7		ALC	ALC
Pier 35, north San Francisco	2	4/22/88	Compstd 1' core	50%	bivalve	Y	22.7		P	PORTSF
Pier 27, north San Francisco	5	4/22/88	Compstd 1' core	50%	bivalve	Y	20		P	PORTSF
Pier 48, China Basin	6	4/22/88	Compstd 1' core	50%	bivalve	N	2.3		P	PORTSF
Pier 80, east of pier	9	4/22/88	Compstd 1' core	50%	bivalve	N	0		P	PORTSF
Pier 80, Islais Ceek	10	4/22/88	Compstd 1' core	50%	bivalve	N	0		P	ISLAIS
Pier 45, north San Francisco	12	4/22/88	Compstd 1' core	50%	bivalve	Y	20		P	PORTSF
Alcatraz disposal site	Ref. 13	4/22/88	Composited core	50%	bivalve	N	0		ALC	ALC
Richmond Inner Harbor (11)										
Point. Potrero Turn	Sect. 3	1/5/88	Composited core	100%	bivalve	Y	24.1		P	RICH
Santa Fe Channel	Sect. 5	1/5/88	Composited core	100%	bivalve	Y	100		P	RICH
Alcatraz disposal site	Sect. D	1/5/88	Composited core	100%	bivalve	Y	26.2		ALC	ALC
Point. Potrero Turn	Sect. 3	1/5/88	Composited core	50%	bivalve	N	9.2		P	RICH
Santa Fe Channel	Sect. 5	1/5/88	Composited core	50%	bivalve	N	33.1		P	RICH
Alcatraz disposal site	Sect. D	1/5/88	Composited core	50%	bivalve	N	9.3		ALC	ALC

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Oakland Inner Harbor (12)										
Entrance channel	Sect. 2	1/6/88	Composited core	100%	bivalve	Y	100		P	OAKIN
Inner harbor reach	Sect. 3	1/6/88	Composited core	100%	bivalve	Y	100		P	OAKIN
Alcatraz Disposal site	Sect. B	1/8/88	Composited core	100%	bivalve	Y	100		ALC	ALC
Entrance channel	Sect. 2	1/6/88	Composited core	50%	bivalve	Y	100		P	OAKIN
Inner harbor reach	Sect. 3	1/6/88	Composited core	50%	bivalve	?	69.9		P	OAKIN
Alcatraz Disposal site	Sect. B	1/8/88	Composited core	50%	bivalve	?	33.8		ALC	ALC
Oakland Harbor Charact (13)										
Inner Entrance channel	Sect. 2	Nov- 88	Composited core	100%	bivalve	Y	16.5		P	OAKIN
Inner harbor reach	Sect. 3	Nov- 88	Composited core	100%	bivalve	Y	20		P	OAKIN
Outer harbor entrance	Sect. 1	Nov- 88	Composited core	100%	bivalve	N	3.3		P	OAKOUT
Lower outer harbor channel	Sect. 2	Nov- 88	Composited core	100%	bivalve	N	4.1		P	OAKOUT
Alcatraz disposal site	Sect. C,D	Nov- 88	Composited core	100%	bivalve	Y	11.1		ALC	ALC
Inner Entrance channel	Sect. 2	Nov- 88	Composited core	50%	bivalve	N	1.4		P	OAKIN
Inner harbor reach	Sect. 3	Nov- 88	Composited core	50%	bivalve	N	2.3		P	OAKIN
Outer harbor entrance	Sect. 1	Nov- 88	Composited core	50%	bivalve	N	1.5		P	OAKOUT
Lower outer harbor channel	Sect. 2	Nov- 88	Composited core	50%	bivalve	N	1.1		P	OAKOUT
Alcatraz disposal site	Sect. C,D	Nov- 88	Composited core	50%	bivalve	N	1.4		ALC	ALC
Richmond Harbor Charact (14)										
Inner harbor channel	Sect. 4	Nov- 88	Composited core	100%	bivalve	Y	75.6		P	RICH
Santa Fe channel	Sect. 5	Nov- 88	Composited core	100%	bivalve	N	5.3		P	RICH
Head of channel	Sect. 6	Nov- 88	Composited core	100%	bivalve	N	2.2		P	RICH
Outer harbor long wharf	Sect. 1	Nov- 88	Composited core	100%	bivalve	Y	99		P	RICH
Southhampton Shoal channel	Sect. 5	Nov- 88	Composited core	100%	bivalve	N	2.4		B	CEN
Alcatraz disposal site	Sect. A,B	Nov- 88	Composited core	100%	bivalve	N	3.9		ALC	ALC
Alcatraz disposal site	Sect. B	Nov- 88	Composited core	100%	bivalve	Y	99.1		ALC	ALC
Inner harbor channel	Sect. 4	Nov- 88	Composited core	50%	bivalve	N	41.7		P	RICH
Santa Fe channel	Sect. 5	Nov- 88	Composited core	50%	bivalve	N	3.6		P	RICH
Head of channel	Sect. 6	Nov- 88	Composited core	50%	bivalve	N	1.9		P	RICH
Outer harbor long wharf	Sect. 1	Nov- 88	Composited core	50%	bivalve	N	2.7		P	RICH
Southhampton Shoal channel.	Sect. 5	Nov- 88	Composited core	50%	bivalve	N	2.7		B	CEN
Alcatraz disposal site	Sect. A,B	Nov- 88	Composited core	50%	bivalve	N	3.1		ALC	ALC
Alcatraz disposal site	Sect. B	Nov- 88	Composited core	50%	bivalve	N	46.4		ALC	ALC
Castro Cove Chevron(15)	Susp. phase									
southwest San Pablo Bay	Ref.	May-87	Compstd 2' core	100%	bivalve	Y	13.9		B	SPB
Inner Castro Cove	12	May-87	Compstd 2' core	100%	bivalve	N	9.3		P	CAS
Inner Castro Cove	13	May-87	Compstd 2' core	100%	bivalve	Y	30.5		P	CAS
Outer Castro Cove	14	May-87	Compstd 2' core	100%	bivalve	Y	23.9		P	CAS
off Point San Pablo	16	May-87	Compstd 2' core	100%	bivalve	Y	21.1		B	SPB
off West Beach, Washington	Control			100%	bivalve	N	7.7		CTL	CTL

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southwest San Pablo Bay	Ref.	May-87	Compstd 2' core	50%	bivalve	Y	9.6		B	SPB
Inner Castro Cove	12	May-87	Compstd 2' core	50%	bivalve	Y	11.4		P	CAS
Inner Castro Cove	13	May-87	Compstd 2' core	50%	bivalve	Y	24		P	CAS
Outer Castro Cove	14	May-87	Compstd 2' core	50%	bivalve	Y	28.4		P	CAS
off Point San Pablo	16	May-87	Compstd 2' core	50%	bivalve	Y	15.8		B	SPB
off West Beach, Washington	Control			50%	bivalve	N	NA		CTL	CTL
southwest San Pablo Bay	Ref.	May-87	Compstd 2' core	*Rhepoxynius*	amphipod	N	9		B	SPB
Inner Castro Cove	12	May-87	Compstd 2' core	*Rhepoxynius*	amphipod	Y	39		P	CAS
Inner Castro Cove	13	May-87	Compstd 2' core	*Rhepoxynius*	amphipod	Y	52		P	CAS
Outer Castro Cove	14	May-87	Compstd 2' core	*Rhepoxynius*	amphipod	Y	90		P	CAS
off Point San Pablo	16	May-87	Compstd 2' core	*Rhepoxynius*	amphipod	N	16		B	SPB
off West Beach, Washington	Control			*Rhepoxynius*	amphipod	N	5		CTL	CTL
EPA South										
Bay Survey (16)										
south of San Mateo Bridge	1	9/24-26/86		*Rhepoxynius*	amphipod		20		B	SOBAY-N
south of San Mateo Bridge	2	9/24-26/86		*Rhepoxynius*	amphipod		50		B	SOBAY-N
south of San Mateo Bridge	3	9/24-26/86		*Rhepoxynius*	amphipod		25		B	SOBAY-N
south of San Mateo Bridge	8	9/24-26/86		*Rhepoxynius*	amphipod		45		B	SOBAY-N
south of San Mateo Bridge	9	9/24-26/86		*Rhepoxynius*	amphipod		30		B	SOBAY-N
south of San Mateo Bridge	10	9/24-26/86		*Rhepoxynius*	amphipod		20		B	SOBAY-N
south of Dumbarton Bridge	4	9/24-26/86		*Rhepoxynius*	amphipod		25		B	SOBAY-S
south of Dumbarton Bridge	5	9/24-26/86		*Rhepoxynius*	amphipod		45		B	SOBAY-S
south of Dumbarton Bridge	6	9/24-26/86		*Rhepoxynius*	amphipod		40		B	SOBAY-S
south of Dumbarton Bridge	7	9/24-26/86		*Rhepoxynius*	amphipod		30		B	SOBAY-S
between San Mateo/Hayward	11	9/24-26/86		*Rhepoxynius*	amphipod		25		B	SOBAY-C
between San Mateo/Hayward	12	9/24-26/86		*Rhepoxynius*	amphipod		50		B	SOBAY-C
between San Mateo/Hayward	13	9/24-26/86		*Rhepoxynius*	amphipod		65		B	SOBAY-C
between San Mateo/Hayward	14	9/24-26/86		*Rhepoxynius*	amphipod		40		B	SOBAY-C
between San Mateo/Hayward	15	9/24-26/86		*Rhepoxynius*	amphipod		60		B	SOBAY-C
between San Mateo/Hayward	16	9/24-26/86		*Rhepoxynius*	amphipod		70		B	SOBAY-C
between San Mateo/Hayward	17	9/24-26/86		*Rhepoxynius*	amphipod		30		B	SOBAY-C
between San Mateo/Hayward	20	9/24-26/86		*Rhepoxynius*	amphipod		55		B	SOBAY-C
between San Mateo/Hayward	21	9/24-26/86		*Rhepoxynius*	amphipod		45		B	SOBAY-C
between San Mateo/Hayward	22	9/24-26/86		*Rhepoxynius*	amphipod		45		B	SOBAY-C
between San Mateo/Hayward	23	9/24-26/86		*Rhepoxynius*	amphipod		100		B	SOBAY-C
between San Mateo/Hayward	24	9/24-26/86		*Rhepoxynius*	amphipod		50		B	SOBAY-C
between San Mateo/Hayward	25	9/24-26/86		*Rhepoxynius*	amphipod		100		B	SOBAY-C
between San Mateo/Hayward	26	9/24-26/86		*Rhepoxynius*	amphipod		40		B	SOBAY-C
Hunters Point	18	9/24-26/86		*Rhepoxynius*	amphipod		35		P	HUN
Hunters Point	19	9/24-26/86		*Rhepoxynius*	amphipod		25		P	HUN
							44.81			

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SBDA Monit: Palo Alto (17)										
West Beach, Washington	Control	Oct-89	N/A		bivalve		4.1		CTL	WESTBCH
Station 1, Dumbarton Bidge	1	Oct-89	N/A		bivalve		3.4		B	SOBAY-S
Station 2, South Bay	2	Oct-89	N/A		bivalve		1.9		P	SOBAY-S
Station 3, South Bay	3	Oct-89	N/A		bivalve		2.4		P	SOBAY-S
Station 1, Dumbarton Br.	1	Oct-89	N/A	*Rhepoxynius*	amphipod		8		B	SOBAY-S
West Beach, Washington	Control	Oct-89	N/A	*Rhepoxynius*	amphipod		6		CTL	WESTBCH
West Beach, Washington	Control	Oct-89	5 ppt sal	*Eohaustorius*	amphipod		0		CTL	WESTBCH
West Beach, Washington	Control	Oct-89	3 um grn size, 28 p	*Eohaustorius*	amphipod		33		CTL	WESTBCH
West Beach, Washington	Control	Oct-89	.5 mm sieve, 28 pp	*Eohaustorius*	amphipod		44		CTL	WESTBCH
West Beach, Washington	Control	Oct-89	.5 mm sieve, 25 pp	*Eohaustorius*	amphipod		25		CTL	WESTBCH
West Beach, Washington	Control	Oct-89	).5 mm sieve, 3 pp	*Eohaustorius*	amphipod		28		CTL	WESTBCH
Station 2, South Bay	2	Oct-89	N/A	*Eohaustorius*	amphipod		50		P	SOBAY-S
Station 3, South Bay	3	Oct-89	N/A	*Eohaustorius*	amphipod		55		P	SOBAY-S
West Beach, Washington	Control	Oct-89	N/A	*Eohaustorius*	amphipod		2		CTL	WESTBCH
Station 1, Dumbarton Br.	1	Oct- 89	N/A	*Eohaustorius*	amphipod		100		B	SOBAY-S
SBDA: Sunnyvale(18)										
Carr Inlet, Washington		Oct-89	N/A	20 g/L	bivalve	N	9.8		CTL	CARR
San Francisco Bay ref. sed.	R-3	Oct-89	N/A	20 g/L	bivalve	N	3.8		B	SPB
So. Bay Deep Chl Ref. Sed.	R-5	Oct-89	N/A	20 g/L	bivalve	N	0.8		B	SOBAY-S
So. Bay Slough Ref. Sed.	R-2/R-4	Oct-89	N/A	20 g/L	bivalve	N	5.2		P	SOBAY-S
Guadalupe Sl.Discharge Sed.	C-1-3	Oct-89	N/A	20 g/L	bivalve	N	3.6		P	SOBAY-S
Carr Inlet, WA		Oct-89	N/A	*Eohaustorius*	amphipod		1		CTL	CARR
Grain size control (sieved)		Oct-89	N/A	*Eohaustorius*	amphipod		9		CTL	CARR
Sieved, 22 ppt		Oct-89	N/A	*Eohaustorius*	amphipod		9		CTL	CARR
Sieved, 5 ppt		Oct-89	N/A	*Eohaustorius*	amphipod		1		CTL	CARR
Sieved, 25 ppt.		Oct-89	N/A	*Eohaustorius*	amphipod		8		CTL	CARR
Guadalupe Sl. Disch., 23 ppt.	C-1-3-1	Oct-89	N/A	*Eohaustorius*	amphipod		43		P	SOBAY-S
Carr Inlet, WA. unsieved		Oct-89	N/A	*Rhepoxynius*	amphipod		2		CTL	CARR
Carr Inlet, WA. sieved		Oct-89	N/A	*Rhepoxynius*	amphipod		3		CTL	CARR
Carr Inlet, WA. sieved, 31 ppt		Oct-89	N/A	*Rhepoxynius*	amphipod		39		CTL	CARR
S F Bay reference R-3	R-3	Oct-89	N/A	*Rhepoxynius*	amphipod		15		B	SPB
S.B. Deep chl ref.	SB5-1	Oct-89	N/A	*Rhepoxynius*	amphipod		38		B	SOBAY-S
S.B. slough ref.	R2-1	Oct-89	N/A	*Rhepoxynius*	amphipod		31		P	SOBAY-S
Port of Oakland, Berth 36 (20)										
Berth 36	<37'	Aug-89	Composited core	100%	bivalve	N	8.5		P	OAKOUT
Berth 36	<37'	Aug-89	Composited core	50%	bivalve	N	6.3		P	OAKOUT
Alcatraz disposal site	ALC	Aug-89	Core	100%	bivalve	N	5.9		ALC	ALC

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Port of Oakland, Berths 30/31 (21)										
Inner Harbor, 1A3/1A4	1A3/1A4	Feb-90	Composited core	100%	urchin	N		97.3	P	OAKIN
Inner Harbor, 1B1/1B4	1B1/1B4	Feb-90	Composited core	100%	urchin	N		98.3	P	OAKIN
Inner Harbor, 1C1/1C4	1C1/1C4	Feb-90	Composited core	100%	urchin	Y		91.7	P	OAKIN
Inner Harbor, 1D1/1D3	1D1/1D3	Feb-90	Composited core	100%	urchin	N		97	P	OAKIN
Inner Harbor, 1E1/1E4	1E1/1E4	Feb-90	Composited core	100%	urchin	N		97.7	P	OAKIN
Alcatraz disposal site	ALC	Feb-90	Composited core	100%	urchin	N		99	ALC	ALC
Inner Harbor, 1A3/1A4	1A3/1A4	Feb-90	Composited core	50%	urchin	N		98	P	OAKIN
Inner Harbor, 1B1/1B4	1B1/1B4	Feb-90	Composited core	50%	urchin	N		98	P	OAKIN
Inner Harbor, 1C1/1C4	1C1/1C4	Feb-90	Composited core	50%	urchin	Y		96.3	P	OAKIN
Inner Harbor, 1D1/1D3	1D1/1D3	Feb-90	Composited core	50%	urchin	N		97.7	P	OAKIN
Inner Harbor, 1E1/1E4	1E1/1E4	Feb-90	Composited core	50%	urchin	N		97.7	P	OAKIN
Port of Oakland, Berth 23 (22)										
Inner Harbor, A/B/C/D	23	Apr-90	Composited core	100%	urchin	Y		42	P	OAKIN
Alcatraz disposal site	ALC	Apr-90	Composited core	100%	urchin	N		86.3	ALC	ALC
Inner Harbor, A/B/C/D	Berth 23	Apr-90	Composited core	50%	urchin	N		71	P	OAKIN
Port of Oakland, Berth 24 (23)										
Inner Harbor, berth 24	Berth 24	Sept-89	Composited core	100%	bivalve	N	5.4		P	OAKIN
Alcatraz disposal site	ALC	Sept-89	Composited core	100%	bivalve	N	7.7		ALC	ALC
Inner Harbor, berth 24	Berth 24	Sept-89	Composited core	50%	bivalve	N	6		P	OAKIN
Port of Oakland, Berth 32 (24)										
Inner Harbor, berth 32	Berth 32	Sept-89	Composited core	100%	bivalve	Y	15.5		P	OAKIN
Inner Harbor, berth 32	Berth 32	Sept-89	Composited core	50%	bivalve	Y	16.1		P	OAKIN
Alcatraz disposal site	ALC	Sept-89	Composited core	100%	bivalve	N	7.7		ALC	ALC
Port of Oakland, Berth 33 (25)										
Inner Harbor, berth 33	Stn. 18-20	Sept-89	Composited core	100%	bivalve	Y	23.2		P	OAKIN
Inner Harbor, berth 33	Stn. 21-23	Sept-89	Composited core	100%	bivalve	N	14.1		P	OAKIN
Alcatraz disposal site	ALC	Sept-89	Composited core	100%	bivalve	N	7.7		ALC	ALC

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Inner Harbor, berth 33	Stn. 18-20	Sept- 89	Composited core	50%	bivalve	N	15.4		P	OAKIN
Inner Harbor, berth 33	Stn. 21-23	Sept- 89	Composited core	50%	bivalve	N	15.8		P	OAKIN
Port of Oakland, Berth 35 (26)										
Inner Harbor	Stn. 1-3	Aug- 89	Composited core	100%	bivalve	N	12.8		P	OAKIN
Inner Harbor	Stn. 4-6	Aug- 89	Composited core	100%	bivalve	N	8.1		P	OAKIN
Inner Harbor	Stn. 1-3	Aug- 89	Composited core	50%	bivalve	N	14.4		P	OAKIN
Inner Harbor	Stn. 4-6	Aug- 89	Composited core	50%	bivalve	N	4.8		P	OAKIN
Alcatraz disposal site	ALC	Aug- 89	Composited core	100%	bivalve	N	5.9		ALC	ALC
Naval Supply Center (27)										
Middle Harbor Composite A	A	Jan- 90	Composited core	100%	bivalve	Y	25.4		P	OAKMID
Middle Harbor Composite A	B	Jan- 90	Composited core	100%	bivalve	Y	18.7		P	OAKMID
Middle Harbor Composite A	C	Jan- 90	Composited core	100%	bivalve	Y	41.7		P	OAKMID
Middle Harbor Composite A	A	Jan- 90	Composited core	50%	bivalve	Y	22.3		P	OAKMID
Middle Harbor Composite A	B	Jan- 90	Composited core	50%	bivalve	Y	15.3		P	OAKMID
Middle Harbor Composite A	C	Jan- 90	Composited core	50%	bivalve	Y	21		P	OAKMID
Alcatraz Disposal Site	ALC	Jan- 90	Composited core	100%	bivalve	N	7.7		ALC	ALC
Oakland Outer Harbor (28)										
Outer Harbor	Sect. 2	Jan- 88	Composited core	100%	bivalve	Y	9.7		P	OAKOUT
Outer Harbor	Sect. 5	Jan- 88	Composited core	100%	bivalve	Y	100		P	OAKOUT
Outer Harbor	Sect. 2	Jan- 88	Composited core	50%	bivalve	N	6.8		P	OAKOUT
Outer Harbor	Sect. 5	Jan- 88	Composited core	50%	bivalve	Y	100		P	OAKOUT
Alcatraz disposal site	ALC	Jan- 88	Composited core	100%	bivalve	Y	17.6		ALC	ALC
Richmond Inner Harbor (29)										
Inner Harbor Channel	Sect. 4	Feb- 89	Composited core	100%	bivalve	Y	75.6		P	RICHIN
Inner Harbor Channel	Sect. 4	Feb- 89	Composited core	50%	bivalve	N	41.7		P	RICHIN
Alcatraz disposal site	ALC	Feb- 89	Composited core	100%	bivalve	Y	99.1		ALC	ALC
Richmond (30) Inner/outer harbor										
Inner Harbor, Section 1	Sect. 1	Dec- 89	Composited core	100%	bivalve	N	17.7		P	RICHIN
Inner Harbor, Section 2	Sect. 2	Dec- 89	Composited core	100%	bivalve	Y	100		P	RICHIN
Inner Harbor, Section 3	Sect. 3	Dec- 89	Composited core	100%	bivalve	Y	100		P	RICHIN
Inner Harbor, Section 4	Sect. 4	Dec- 89	Composited core	100%	bivalve	Y	99.4		P	RICHIN

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Inner Harbor, Section 1	Sect. 1	Dec-89	Composited core	50%	bivalve		7.9		P	RICHIN
Inner Harbor, Section 2	Sect. 2	Dec-89	Composited core	50%	bivalve		29.6		P	RICHIN
Inner Harbor, Section 3	Sect. 3	Dec-89	Composited core	50%	bivalve		58.8		P	RICHIN
Inner Harbor, Section 4	Sect. 4	Dec-89	Composited core	50%	bivalve		27.7		P	RICHIN
Outer Harbor, Section 1	Sect. 1	Dec-89	Composited core	100%	bivalve	Y	100		P	RICHOUT
Outer Harbor, Section 2	Sect. 2	Dec-89	Composited core	100%	bivalve	Y	29.9		P	RICHOUT
Outer Harbor, Section 1	Sect. 1	Dec-89	Composited core	50%	bivalve		43.3		P	RICHOUT
Outer Harbor, Section 2	Sect. 2	Dec-89	Composited core	50%	bivalve		9.8		P	RICHOUT
Alcatraz disposal site	ALC	Dec-89	Composited core	100%	bivalve	Y	99.2		ALC	ALC
Suisun Slough Channel (31)										
Section 1	Sect. 1	Apr-90	Composited core	100%	bivalve	Y	97.7		P	SUISUN
Section 2	Sect. 2	Apr-90	Composited core	100%	bivalve	Y	99.2		P	SUISUN
Section 1	Sect. 1	Apr-90	Composited core	50%	bivalve		30.5		P	SUISUN
Section 2	Sect. 2	Apr-90	Composited core	50%	bivalve		55.1		P	SUISUN
Carquinez Strait disposal site	CAR.	Apr-90	Composited core	100%	bivalve	Y	96.5		CAR	CAR
Treasure Island Naval Base (32)										
Treasure Island Navy pier 503	Compos. A	Feb-90	Composited core	100%	bivalve	Y	23.5		P	TI
Treasure Island Navy pier 503	Compos. B	Feb-90	Composited core	100%	bivalve	Y	22.8		P	TI
Treasure Island Navy pier 503	Compos. C	Feb-90	Composited core	100%	bivalve	Y	27.5		P	TI
Treasure Island Navy pier 503	Compos. D	Feb-90	Composited core	100%	bivalve	Y	24.1		P	TI
Treasure Island Navy pier 503	Compos. E	Feb-90	Composited core	100%	bivalve	Y	24.3		P	TI
Alcatraz disposal site	ALC	Feb-90	Composited core	100%	bivalve	N	7.7		ALC	ALC
Treasure Island Navy pier 503	Compos. A	Feb-90	Composited core	50%	bivalve	Y	18.4		P	TI
Treasure Island Navy pier 503	Compos. B	Feb-90	Composited core	50%	bivalve	Y	17.2		P	TI
Treasure Island Navy pier 503	Compos. C	Feb-90	Composited core	50%	bivalve	Y	13.9		P	TI
Treasure Island Navy pier 503	Compos. D	Feb-90	Composited core	50%	bivalve	Y	12.5		P	TI
Treasure Island Navy pier 503	Compos. E	Feb-90	Composited core	50%	bivalve	Y	10.4		P	TI
Port of San Francisco 1990 (33)										
Pier 35 south	1	Aug-89	Composited core	100%	bivalve		100		P	PORTSF
Pier 35 north	2	Aug-89	Composited core	100%	bivalve		2		P	PORTSF
Fish/wharf breakwater	3	Aug-89	Composited core	100%	bivalve		95		P	PORTSF
Pier 94 berth	4	Aug-89	Composited core	100%	bivalve		4		P	PORTSF
Islais Creek approach	5	Aug-89	Composited core	100%	bivalve		96		P	PORTSF
Pier 94 north approach	6	Aug-89	Composited core	100%	bivalve		28		P	PORTSF
Pier 48 east	7	Aug-89	Composited core	100%	bivalve		28		P	PORTSF
Pier 48 west	8	Aug-89	Composited core	100%	bivalve		100		P	PORTSF

Survey/Location	Station	Date	Sample	Amphipod Species Sediment Concentration	Bioassay	Significant No Hit (N)	Amphipod % mortality/	Urchin %	Basin/	Geographic Region
Pier 70	9	Aug-89	Composited core	100%	bivalve		94		P	PORTSF
Pier 70	10	Aug-89	Composited core	100%	bivalve		6		P	PORTSF
Pier 94 south approach	11	Aug-89	Composited core	100%	bivalve		1		P	PORTSF
Pier 29	12	Aug-89	Composited core	100%	bivalve		23		P	PORTSF
Alcatraz disposal site		Aug-89	Composited core	100%	bivalve		100		ALC	ALC
Pier 35 south	1	Aug-89	Composited core	50%	bivalve		37		P	PORTSF
Pier 35 north	2	Aug-89	Composited core	50%	bivalve		4		P	PORTSF
Fish/wharf breakwater	3	Aug-89	Composited core	50%	bivalve		5		P	PORTSF
Pier 94 berth	4	Aug-89	Composited core	50%	bivalve		5		P	PORTSF
Islais Creek approach	5	Aug-89	Composited core	50%	bivalve		81		P	PORTSF
Pier 94 north approach	6	Aug-89	Composited core	50%	bivalve		0.3		P	PORTSF
Pier 48 east	7	Aug-89	Composited core	50%	bivalve		1.3		P	PORTSF
Pier 48 west	8	Aug-89	Composited core	50%	bivalve		3		P	PORTSF
Pier 70	9	Aug-89	Composited core	50%	bivalve		0		P	PORTSF
Pier 70	10	Aug-89	Composited core	50%	bivalve		0.3		P	PORTSF
Pier 94 south approach	11	Aug-89	Composited core	50%	bivalve		0.3		P	PORTSF
Pier 29	12	Aug-89	Composited core	50%	bivalve		1		P	PORTSF
Alameda NAS (34)										
Alameda	1	Feb/Mar 88	Composited core	100%	bivalve	N	7.3		P	ANB
Offshore reference site	2	Feb/Mar 88	Composited core	100%	bivalve		9.7		OFFSHORE	OFFSHORE
Alcatraz disposal site	3	Feb/Mar 88	Composited core	100%	bivalve		33.3		ALC	ALC
Alameda	1	Feb/Mar 88	Composited core	50%	bivalve		4		P	ANB
Offshore reference site	2	Feb/Mar 88	Composited core	50%	bivalve		11.3		OFFSHORE	OFFSHORE
Alcatraz disposal site	3	Feb/Mar 88	Composited core	50%	bivalve		50		ALC	ALC
Oakland Middle Harbor (35)										
Middle Harbor 1 and 2	1,2	Feb/Mar 88	Composited core	100%	bivalve	Y	66.3		P	OakMid
Middle Harbor 3	3	Feb/Mar 88	Composited core	100%	bivalve	Y	50.3		P	OakMid
Middle Harbor 4, 5, 6	4,5,6	Feb/Mar 88	Composited core	100%	bivalve	Y	56		P	OakMid
Offshore Reference	Offshore	Feb/Mar 88	Composited core	100%	bivalve		11.3		OFFSHORE	Offshore
Alcatraz disposal site	ALC	Feb/Mar 88	Composited core	100%	bivalve		50		ALC	ALC
Middle Harbor 1 and 2	1,2	Feb/Mar 88	Composited core	50%	bivalve	Y	24.7		P	OakMid
Middle Harbor 3	3	Feb/Mar 88	Composited core	50%	bivalve	Y	24.7		P	OakMid
Middle Harbor 4,5,6	4,5,6	Feb/Mar 88	Composited core	50%	bivalve	Y	25.3		P	OakMid
Offshore Reference	Offshore	Feb/Mar 88	Composited core	50%	bivalve	Y	8.7		OFFSHORE	Offshore
Alcatraz disposal site	ALC	Feb/Mar 88	Composited core	50%	bivalve	Y	33.3		ALC	ALC
Hunters Point Drydock 4 (36)										
Hunters Point Drydock 4	1	1987	Composited core	*Rhepoxynius*	amphipod	Y	66		P	HUN
Offshore reference site	Offshore	1987	Composited core	*Rhepoxynius*	amphipod	N	10		Offshore	Offshore
Hunters Point Drydock 4	1	1987	Composited core	100%	bivalve	N	18.3		P	HUN

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Hunters Point Reassessment (37)										
Hunters Point 3	3 Upper	Mar- 87	Composited core	*Rhepoxynius*	amphipod	Y	53		P	HUN
Hunters Point 3	3 Lower	Mar- 87	Composited core	*Rhepoxynius*	amphipod	Y	33		P	HUN
Hunters Point 3	3 Upper	Mar- 87	Composited core	100%	bivalve	N	12.3		P	HUN
Hunters Point 3	3 Lower	Mar- 87	Composited core	100%	bivalve	Y	100		P	HUN
Offshore Reference site	Offshore	Mar- 87	Composited core	100%	bivalve	N	11.3		Offshore	Offshore
Mare Island. Strait (38)										
Lower	1	Nov - 89	Composited core	100%	bivalve	Y	98.5		P	Mare
Lower	2	Nov - 89	Composited core	100%	bivalve	Y	46.1		P	Mare
Middle	3	Nov - 89	Composited core	100%	bivalve	Y	74.2		P	Mare
Middle	4	Nov - 89	Composited core	100%	bivalve	Y	99.6		P	Mare
Upper	5	Nov - 89	Composited core	100%	bivalve	Y	91.3		P	Mare
Upper	6	Nov - 89	Composited core	100%	bivalve	Y	92.2		P	Mare
Carquinez disposal site	CAR	Nov- 89	Composited core	100%	bivalve		30.9		CAR	CAR
Lower	1	Nov - 89	Composited core	50%	bivalve		30.2		P	Mare
Lower	2	Nov - 89	Composited core	50%	bivalve		36.4		P	Mare
Middle	3	Nov - 89	Composited core	50%	bivalve		30.4		P	Mare
Middle	4	Nov - 89	Composited core	50%	bivalve		28.1		P	Mare
Upper	5	Nov - 89	Composited core	50%	bivalve		37.7		P	Mare
Upper	6	Nov - 89	Composited core	50%	bivalve		25.8		P	Mare
				50%						
Carquinez disposal site	CAR	Nov- 89	Composited core	50%	bivalve		26.1		CAR	CAR
Piers 80 and 94 (39)										
Off Islais Creek	Sect. 1	Dec- 89	Composited core	100%	bivalve	Y	31.4		P	PORTSF
Off Islais Creek	Sect. 3	Dec- 89	Composited core	100%	bivalve	N	100		P	PORTSF
Alcatraz disposal site	ALC	Dec- 89	Composited core	100%	bivalve	Y	24.1		ALC	ALC
Off Islais Creek	Sect. 1	Dec- 89	Composited core	50%	bivalve		15		P	PORTSF
Off Islais Creek	Sect. 3	Dec- 89	Composited core	50%	bivalve		41.1		P	PORTSF
Alcatraz disposal site	ALC	Dec- 89	Composited core	50%	bivalve		18.7		ALC	ALC
Mare Island Analysis (40)										
Mare #2	2	Dec- 87	Composited core	100%	bivalve	N	97.3		P	MARE
Mare #3	3	Dec- 87	Composited core	100%	bivalve	N	98.3		P	MARE
Carquinez disposal site	CAR	DEc- 87	Composited core	100%	bivalve	N	99.7		CAR	CAR
Mare #2	2	Dec- 87	Composited core	50%	bivalve	N	97.3		P	MARE
Mare #3	3	Dec- 87	Composited core	50%	bivalve	N	87		P	MARE

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Carquinez disposal site	CAR	Dec-87	Composited core	50%	bivalve	N	98		CAR	CAR
Santa Fe/Richmond (41)										
Sante Fe Channel	1	Nov/Dec 86	Composited core	*Rhepoxynius*	amphipod	Y	38		P	RICHIN
Richmond Inner Harbor	2	Nov/Dec 86	Composited core	*Rhepoxynius*	amphipod	Y	16		P	RICHIN
Oakland Harbor (42)										
Inner Harbor	1-2	Jan-90	Composited core	100%	bivalve	Y	17.9		P	OAKIN
Inner Harbor	3	Jan-90	Composited core	100%	bivalve	N	13.9		P	OAKIN
Inner Harbor	4	Jan-90	Composited core	100%	bivalve	N	14.9		P	OAKIN
Inner Harbor	5	Jan-90	Composited core	100%	bivalve	N	9.4		P	OAKIN
Outer Harbor	1	Jan-90	Composited core	100%	bivalve	Y	18.8		P	OAKOUT
Outer Harbor	2-3	Jan-90	Composited core	100%	bivalve	N	16		P	OAKOUT
Outer Harbor	4,5,6	Jan-90	Composited core	100%	bivalve	Y	96.2		P	OAKOUT
Alcatraz disposal site	ALC	Jan-90	Composited core	100%	bivalve	Y	18.6		ALC	ALC
Inner Harbor	1-2	Jan-90	Composited core	50%	bivalve		13.4		P	OAKIN
Inner Harbor	3	Jan-90	Composited core	50%	bivalve		11.9		P	OAKIN
Inner Harbor	4	Jan-90	Composited core	50%	bivalve		18.3		P	OAKIN
Inner Harbor	5	Jan-90	Composited core	50%	bivalve		11.5		P	OAKIN
Outer Harbor	1	Jan-90	Composited core	50%	bivalve		11.2		P	OAKOUT
Outer Harbor	2-3	Jan-90	Composited core	50%	bivalve		14.7		P	OAKOUT
Outer Harbor	4,5,6	Jan-90	Composited core	50%	bivalve		18.2		P	OAKOUT
Alcatraz disposal site	ALC	Jan-90	Composited core	50%	bivalve		17.3		ALC	ALC
UNOCAL MARINE Terminal (43)										
off Rodeo, Area 1	1	July-90	Composited core	100%	bivalve		9		P	UNOCAL
off Rodeo, Area 2	2	July-90	Composited core	100%	bivalve		11		P	UNOCAL
off Rodeo, Area 4	4	July-90	Composited core	100%	bivalve		8.6		P	UNOCAL
Carquinez disoposal site	CAR	July-90	Composited core	100%	bivalve		18.8		CAR	CAR
off Rodeo, Area 1	1	July-90	Composited core	50%	bivalve		9.6		P	UNOCAL
off Rodeo, Area 2	2	July-90	Composited core	50%	bivalve		19.5		P	UNOCAL
off Rodeo, Area 4	4	July-90	Composited core	50%	bivalve		19.6		P	UNOCAL
Carquinez disoposal site	CAR	July-90	Composited core	50%	bivalve		13.1		CAR	CAR
Pacific Refinery Pier (44)										
San Pablo Bay	1	Feb-90	Composited core	100%	bivalve	Y	26.4		P	PACREF
San Pablo Bay	2	Feb-90	Composited core	100%	bivalve	Y	25.7		P	PACREF
San Pablo Bay	3	Feb-90	Composited core	100%	bivalve	Y	19.9		P	PACREF
Carquinez disposal site	CAR	Feb-90	Composited core	100%	bivalve	N	15.3		CAR	CAR

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
San Pablo Bay	1	Feb-90	Composited core	50%	bivalve	Y	15.8		P	PACREF
San Pablo Bay	2	Feb-90	Composited core	50%	bivalve	Y	15.8		P	PACREF
San Pablo Bay	3	Feb-90	Composited core	50%	bivalve	Y	17		P	PACREF
Carquinez disposal site	CAR	Feb-90	Composited core	50%	bivalve	N	16.2		CAR	CAR
Pacific Refinery Pier (45)										
San Pablo Bay	1	N/A	Composited core	100%	bivalve	Y	19.2		P	PACREF
San Pablo Bay	1	N/A	Composited core	50%	bivalve	Y	23.1		P	PACREF
Carquinez disposal site	CAR	N/A	Composited core	100%	bivalve	N	44.7		CAR	CAR
Carquinez disposal site	CAR	N/A	Composited core	50%	bivalve	N	7.7		CAR	CAR
Oakland Berth 21 (46)										
Berth 21	1	Sept-89	Composited core	100%	bivalve	N	7.6		P	OAKOUT
Berth 21	1	Sept-89	Composited core	50%	bivalve	N	4.5		P	OAKOUT
Alcatraz disposal site	ALC	sept-89	Composited core	100%	bivalve	N	7.7		ALC	ALC
Oakland Berth 20 (47)										
Berth 20	1,3	Sept-89	Composited core	100%	bivalve	N	12.8		P	OAKOUT
Berth 20	4,6	Sept-89	Composited core	100%	bivalve	N	8.4		P	OAKOUT
Berth 20	1,3	Sept-89	Composited core	50%	bivalve	Y	14.6		P	OAKOUT
Berth 20	4,6	Sept-89	Composited core	50%	bivalve	N	8.4		P	OAKOUT
Alcatraz disposal site	ALC	sept-89	Composited core	100%	bivalve	N	7.7		ALC	ALC
Oakland Berths 30, 31 (48)										
Stations 1a1-1a4	A	Feb-90	Composited core	100%	urchin	N		98.7	P	OAKOUT
Stations 1B1-1B4	B	Feb-90	Composited core	100%	urchin	Y		97	P	OAKOUT
Stations 1C1-1C4	C	Feb-90	Composited core	100%	urchin	Y		38.7	P	OAKOUT
Stations 1D1-1D4	D	Feb-90	Composited core	100%	urchin	Y		96.3	P	OAKOUT
Stations 1E1-1E4	E	Feb-90	Composited core	100%	urchin	Y		96.3	P	OAKOUT
Alcatraz disposal site	ALC	Feb-90	Composited core	100%	urchin	N		99	ALC	ALC
Oakland Outer Harbor Mounds (49)										
Station A	A	Sept-89	Composited core	100%	bivalve	N	7.3		P	OAKOUT
Station B	B	Sept-89	Composited core	100%	bivalve	N	4.1		P	OAKOUT
Station A	A	Sept-89	Composited core	50%	bivalve	N	7.1		P	OAKOUT
Station B	B	Sept-89	Composited core	50%	bivalve	N	6.5		P	OAKOUT
Alcatraz disposal site	ALC	Sept-89	Composited core	100%	bivalve	N	13.5		ALC	ALC

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
Oakland Berth 38 (50)										
Berth 38	38	Apr-90	Composited core	100%	urchin	N		71.7	P	OAKOUT
Berth 38	38	Apr-90	Composited core	50%	urchin	Y		51.3	P	OAKOUT
Alcatraz disposal site	ALC	Apr-90	Composited core	100%	urchin	Y		66.30%	ALC	ALC
Oakland Berth 22 (51)										
Berth 22-1	1	Jan-90	Composited core	100%	bivalve	Y	7.8		P	OAKOUT
Berth 22-2	2	Jan-90	Composited core	100%	bivalve	Y	13.4		P	OAKOUT
Berth 22-1	1	Jan-90	Composited core	50%	bivalve	Y	10.8		P	OAKOUT
Berth 22-2	2	Jan-90	Composited core	50%	bivalve	Y	12.8		P	OAKOUT
Alcatraz disposal site	ALC	Jan-90	Composited core	100%	bivalve	Y	13.4		ALC	ALC
Moffett Field NAS (52)										
Guadalupe Slough	A	May-88	Composited core	100%	bivalve	Y	100		P	GUADASL
Guadalupe Slough	B	May-88	Composited core	100%	bivalve	Y	100		P	GUADASL
Guadalupe Slough	C	May-88	Composited core	100%	bivalve	Y	100		P	GUADASL
Guadalupe Slough	D	May-88	Composited core	100%	bivalve	Y	100		P	GUADASL
Guadalupe Slough	A	May-88	Composited core	50%	bivalve	Y	100		P	GUADASL
Guadalupe Slough	B	May-88	Composited core	50%	bivalve	Y	100		P	GUADASL
Guadalupe Slough	C	May-88	Composited core	50%	bivalve	Y	100		P	GUADASL
Guadalupe Slough	D	May-88	Composited core	50%	bivalve	Y	68.3		P	GUADASL
Alcatraz disposal site	ALC	May-88	Composited core	100%	bivalve	N	0		ALC	ALC
Guadalupe Slough (53)										
Guadalupe Slough	A	June-89	Composited core	100%	bivalve	Y	100		P	GUADASL
Guadalupe Slough	B	June-89	Composited core	100%	bivalve	Y	97.8		P	GUADASL
Guadalupe Slough	C	June-89	Composited core	100%	bivalve	Y	98.7		P	GUADASL
Guadalupe Slough	D	June-89	Composited core	100%	bivalve	Y	87.8		P	GUADASL
Guadalupe Slough	A	June-89	Composited core	50%	bivalve	Y	98.5		P	GUADASL
Guadalupe Slough	B	June-89	Composited core	50%	bivalve	Y	88.2		P	GUADASL
Guadalupe Slough	C	June-89	Composited core	50%	bivalve	Y	43.8		P	GUADASL
Guadalupe Slough	D	June-89	Composited core	50%	bivalve	Y	98.9		P	GUADASL
Alcatraz disposal site	ALC	June-89	Composited core	100%	bivalve	Y	72.7		ALC	ALC
Guadalupe Slough	A	June-89	Composited core	*Rhepoxynius*	amphipod	N	20		P	GUADASL
Guadalupe Slough	B	June-89	Composited core	*Rhepoxynius*	amphipod	N	22		P	GUADASL
Guadalupe Slough	C	June-89	Composited core	*Rhepoxynius*	amphipod	N	26		P	GUADASL
Guadalupe Slough	D	June-89	Composited core	*Rhepoxynius*	amphipod	N	18		P	GUADASL
Alcatraz disposal site	ALC	June-89	Composited core	*Rhepoxynius*	amphipod	N	21		ALC	ALC

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
SBDA: San Jose (54)										
Artesian Slough disch. sed	C-1-0	Oct- 89	N/A	*Hyalella*	amphipod	N	15		P	SOBAY-S
South Bay f/water ref.	R-1	Oct- 89	N/A	*Hyalella*	amphipod	N	8		Ref	SOBAY-S
SF Bay reference sed	R-3	Oct- 89	N/A	100%	bivalve	N	3.8		B	SPB
Deep Channel Reference sed.	SB-5	Oct- 89	N/A	100%	bivalve	N	0.8		B	SOBAY-S
Mowry slough reference sed	R-2/R-4	Oct- 89	N/A	100%	bivalve	N	5.2		P	SOBAY-S
Discharge	C-2-5	Oct- 89	N/A	100%	bivalve	N	2		P	SOVAY-S
Discharge	C2-5-2	Oct- 89	N/A	*Eohaustorius*	amphipod	Y	48		P	SOBAY-S
SF Bay Reference	R-3	Oct-89	N/A	*Rhepoxynius*	amphipod		15		B	SPB
Deep Channel Reference	SB5-1	Oct- 89	N/A	*Rhepoxynius*	amphipod		38		B	SOBAY-S
Mowry Slough reference	R-2/R-2	Oct-89	N/A	*Rhepoxynius*	amphipod		31		P	SOBAY-S
SBDA: San Jose (55)										
Artesian Slough, discharge sed	C-1-0	Jan- 90	N/A	*Hyalella*	amphipod	N	6		P	SOBAY-S
South Bay f/water ref.	R-1	Jan- 90	N/A	*Hyalella*	amphipod	N	7		Ref	SOBAY-S
SF Bay reference sed	R-3	Jan- 90	N/A	100%	bivalve	N	7.2		B	SPB
Deep Channel Reference sed.	SB-5	Jan- 90	N/A	100%	bivalve	N	11.2		B	SOBAY-S
Mowry slough reference	R-2/R-4	Jan- 90	N/A	100%	bivalve	N	12.4		P	SOBAY-S
Discharge	C-2-5	Jan- 90	N/A	100%	bivalve	N	19.8		P	SOBAY-S
Discharge sed.	C2-5-1	Jan- 90	N/A	*Eohaustorius*	amphipod	N	36		P	SOBAY-S
Mowry Slough Reference	R-2/R-4	Jan-90	N/A	*Eohaustorius*	amphipod	N	49		P	SOBAY-S
Deep Channel Reference	SB5-1	Jan- 90	N/A	*Eohaustorius*	amphipod	N	40		B	SOBAY-S
SF Bay Reference	R-3	Jan- 90	N/A	*Rhepoxynius*	amphipod	N	37		B	SPB
Deep Channel Reference	SB5-1	Jan-90	N/A	*Rhepoxynius*	amphipod	N	50		B	SOBAY-S
Mowry Slough reference	R-2/R-2	Jan- 90	N/A	*Rhepoxynius*	amphipod	N	42		P	SOBAY-S
SBDA: San Jose (56)										
Artesian Slough disch sed	C-1-0	Mar- 90	N/A	*Hyalella*	amphipod	N	13		P	SOBAY-S
South Bay f/water ref.	R-1	Mar- 90	N/A	*Hyalella*	amphipod	N	47		B	SOBAY-S
SF Bay reference sed	R-3	Mar- 90	N/A	100%	bivalve	N	1.8		B	SPB
Deep Channel Reference sed.	SB-5	Mar- 90	N/A	100%	bivalve	N	1.2		B	SOBAY-S
Mowry slough reference	R-2/R-4	Mar- 90	N/A	100%	bivalve	N	2.4		P	SOBAY-S
Discharge	C-2-5	Mar- 90	N/A	100%	bivalve	N	8.8		P	SOBAY-S
Discharge sed.	C2-5-1	Mar- 90	N/A	*Eohaustorius*	amphipod	N	52		P	SOBAY-S
Mowry Slough Reference	R-2/R-4	Mar- 90	N/A	*Eohaustorius*	amphipod	N	61		P	SOBAY-S
Deep Channel Reference	SB5-1	Mar- 90	N/A	*Eohaustorius*	amphipod	N	86		B	SOBAY-S

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
SF Bay Reference	R-3	Mar-90	N/A	*Rhepoxynius*	amphipod	N	29		B	SPB
Deep Channel Reference	SB5-1	Mar-90	N/A	*Rhepoxynius*	amphipod	N	11		B	SOBAY-S
SBDA: San Jose (57)										
north of Dumbarton Bridge, SB4	Stn. 1	Jan-90		100%	bivalve	N	0.7		B	SOBAY-S
Mayfield slough channel	Stn. 2	Jan-90		100%	bivalve	N	0		P	SOBAY-S
Catwalk at discharge	Stn. 3	Jan-90		100%	bivalve	N	0.5		P	SOBAY-S
north of Dumbarton Bridge, SB4	Stn. 1	Jan-90		*Rhepoxynius*	amphipod	Y	36		B	SOBAY-S
Mayfield slough channel	Stn. 2	Jan-90		*Rhepoxynius*	amphipod	Y	25		P	SOBAY-S
Catwalk at discharge	Stn. 3	Jan-90		*Rhepoxynius*	amphipod	Y	55		P	SOBAY-S
north of Dumbarton Bridge, SB4	Stn. 1	Jan-90		*Eohaustorius*	amphipod	Y	36		B	SOBAY-S
Mayfield slough channel	Stn. 2	Jan-90		*Eohaustorius*	amphipod	N	35		P	SOBAY-S
Catwalk at discharge	Stn. 3	Jan-90		*Eohaustorius*	amphipod	Y	21.5		P	SOBAY-S
SBDA: San Jose (58)										
north of Dumbarton Bridge, SB4	Stn. 1	Mar-90		*Rhepoxynius*	amphipod	Y	34		B	SOBAY-S
Mayfield slough channel	Stn. 2	Mar-90		*Rhepoxynius*	amphipod	N	22.5		P	SOBAY-S
Catwalk at discharge	Stn. 3	Mar-90		*Rhepoxynius*	amphipod	N	18.5		P	SOBAY-S
north of Dumbarton Bridge, SB4	Stn. 1	Mar-90		*Eohaustorius*	amphipod	Y	31.5		B	SOBAY-S
Mayfield slough channel	Stn. 2	Mar-90		*Eohaustorius*	amphipod	Y	45		P	SOBAY-S
Catwalk at discharge	Stn. 3	Mar-90		*Eohaustorius*	amphipod	Y	36.5		P	SOBAY-S
north of Dumbarton Bridge, SB4	Stn. 1	Mar-90		100%	bivalve	N	3		B	SOBAY-S
Mayfield slough channel	Stn. 2	Mar-90		100%	bivalve	N	5.5		P	SOBAY-S
Catwalk at discharge	Stn. 3	Mar-90		100%	bivalve	N	3.25		P	SOBAY-S
SBDA: Sunnyvale (59)										
Guadelupe Slough channel	C-1-1	Jan-90		*Hyalella*	amphipod	N	6		P	GUADASL
Alviso Slough channel	C-2-0	Jan-90		*Hyalella*	amphipod	N	9		P	SOBAY-S
San Francisco Bay reference	R-3	Jan-90		100%	bivalve	N	7.2		B	SPB
Deep Channel reference	SB5	Jan-90		100%	bivalve	Y	11.2		B	SOBAY-S
Mowry slough reference	R-2	Jan-90		100%	bivalve	N	2.4		P	SOBAY-S
Discharge	C-1-3	Jan-90		100%	bivalve	N	11		P	SOBAY-S
Deep Channel reference	SB5	Jan-90		*Eohaustorius*	amphipod	N	40		B	SOBAY-S
Mowry slough reference	R-2	Jan-90		*Eohaustorius*	amphipod		49		P	SOBAY-S
Discharge	C-1-3	Jan-90		*Eohaustorius*	amphipod		32		P	SOBAY-S
San Francisco Bay reference	R-3	Jan-90		*Rhepoxynius*	amphipod	N	37		B	SPB
Deep Channel reference	SB5	Jan-90		*Rhepoxynius*	amphipod	Y	50		B	SOBAY-S
Mowry slough reference	R-2	Jan-90		*Rhepoxynius*	amphipod	N	42		P	SOBAY-S
Discharge	C-5-0-1	Jan-90		*Rhepoxynius*	amphipod	N	30		P	SOBAY-S

Survey/Location (Ref. No.)	Station	Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y)/ No Hit (N)	Amphipod % mortality/ Bivalve % abnormal	Urchin % Fertilization	Basin/ Periphery	Geographic Region
SBDA: Sunnyvale (60)										
Guadelupe Slough channel	C-1-1	Mar-90		*Hyalella*	amphipod	N	12		P	GUADASL
Alviso Slough channel	C-2-0	Mar-90		*Hyalella*	amphipod	N	8		P	SOBAY-S
San Francisco Bay reference	R-3	Mar-90		100%	bivalve	N	1.8		B	SPB
Deep Channel reference	SB5	Mar-90		100%	bivalve	N	1.2		B	SOBAY-S
Mowry slough reference	R-2	Mar-90		100%	bivalve	N	2.4		P	SOBAY-S
Discharge	C-1-3	Mar-90		100%	bivalve	N	1.8		P	SOBAY-S
Deep Channel reference	SB5	Mar-90		*Eohaustorius*	amphipod	N	56		B	SOBAY-S
Mowry slough reference	R-2	Mar-90		*Eohaustorius*	amphipod		61		P	SOBAY-S
Discharge	C-1-3	Mar-90		*Eohaustorius*	amphipod		86		P	SOBAY-S
San Francisco Bay reference	R-3	Mar-90		*Rhepoxynius*	amphipod	N	28		B	SPB
Deep Channel reference	SB5	Mar-90		*Rhepoxynius*	amphipod	Y	11		B	SOBAY-S

OAKIN = Oakland Inner Harbor
OAKOUT = Oakland OuterHarbor
OAKMID = Oakland middle harbor
CEN = Central Bay
SPB = San Pablo Bay
TB = Tomales Bay
TI = Treasure Island Naval Base
ANB = Alameda Naval Base
HUN = Hunters Point Naval Base
SOBAY-N = South Bay, northern part
SOBAY-C= South Bay, central part
SOBAY-S=South Bay, southern part
ISLAIS= Islais Creek Waterway
RED = Redwood Creek channel
ALC = Alcatraz Disposal Site
CAR = Carquinez Disposal Site
SPDS = San Pablo Bay Disposal Site
PTMO = Point Molate
MARE = Mare Island strait
PORTSF = Port of San Francisco docks
RICH = Richmond Harbor channel
RICHIN = Richmond Inner Harbor
RICHOUT = Richmond Outer Harbor
CAS = Castro Cove
CTL = Control (West Beach, Carr Inlet)
SUISUN = Suisun Bay slough
UNOCAL = Unocal dock, Rodeo
PACREF = Pacific Refining dock
GUADASL = Guadalupe Slough

bivalve = mussel or oyster larvae
urchin = urchin larvae
Rhepoxynius = *Rhepoxynius abronius*
Eohaustorius= *Eohaustorius estuarius*
Hyalella= *Hyalella azteca*
N/A = data not available
PSP = Puget Sound Protocols

APPENDIX A

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APPENDIX B

SUMMARY OF SEDIMENT TOXICITY DATA FROM 1990
(ToxScan, Inc.)

			Mussel Larvae				Microtox Assay		Sea Urchin Larvae Cytogenetic Analysis						Mussel Larvae Cytogenetic Analysis			
Sample #	Station #	Ref #	Total No. Larvae	Percent Survival	Number Abnormal	Percent Abnormal	Saline Extractions EC50*	Organic Extractions EC50**	Number of Mitoses per Embryo mean	Number of Mitoses per Embryo S.D	# Telophases Aberrant \total	% Aberrant Telophases	Number Embryos with: >1 micronucleus	Number Embryos with: >1 cytologic abnormality	# Embryos evaluated\35 telophases^	# telophases (aberrant\ total)	% aberrant telophases	# Normal Telophases per Embryo
67	1A-1	2	119	82.3	15	12.6	NT	NT	9.1	3.6	5\43	11.6	0	4	127	6\33	18.2	0.225
68	1A-2	2	93	67.5	15	16.1	NT	0.19	-	-	-	-	-	-	-	-	-	-
69	1A-3	2	132	91.2	22	16.7	NT	0.38	-	-	-	-	-	-	-	-	-	-
70	1B	2	129	91.4	24	18.6	NT	1.48	11.1	2.8	3\41	7.3	0	2	150	7\28	25	0.183
71	1C	2	92	63.6	17	18.5	NT	1.18	9.2	3	5\29	17.2	1	1	112	9\36	25	0.24
72	2A-1	2	111	76.6	14	12.6	NT	4.44	6.7	3.2	6\17	35.3	0	1	103	10\35	28.6	0.243
73	2A-2	2	90	62.2	11	12.2	NT	NT	-	-	-	-	-	-	-	-	-	-
74	2A-3	2	130	89.9	14	10.8	NT	2.36	-	-	-	-	-	-	-	-	-	-
75	2B	2	114	78.8	14	12.3	NT	1.75	8.5	3.3	5\21	23.8	2	5	119	7\35	20	0.235
76	2C	2	144	99.5	18	12.5	NT	3.01	6.9	2.8	5\13	38.5	4	3	145	14\29	48.3	0.125
16	3A-1	1	127	102	0	0	NT	NT	7.7	4.1	10\28	35.7	4	0	99	25\50	50	0.177
77	3A-2	2	101	71.2	14	13.9	NT	NT	-	-	-	-	-	-	-	-	-	-
78	3A-3	2	153	105.8	23	15	NT	NT	-	-	-	-	-	-	-	-	-	-
17	3B	1	120	103.6	1	0.8	NT	NT	7.3	4.1	5\27	18.5	3	3	120	21\35	60	0.117
18	3C	1	128	102.8	1	0.8	NT	NT	9.8	4.4	7\43	16.3	2	1	149	14\35	40	0.175
19	4A-1	1	107	88	1	0.9	NT	NT	7.3	2.9	3\21	14.3	1	3	132	6\30	20	0.2
79	4A-2	2	87	60.1	14	16.1	NT	NT	-	-	-	-	-	-	-	-	-	-
80	4A-3	2	117	80.9	10	8.5	NT	NT	-	-	-	-	-	-	-	-	-	-
20	4B	1	104	83.5	0	0	NT	NT	7.7	3.4	4\27	14.8	0	1	145	13\29	44.8	0.133
21	4C	1	137	110	3	2.2	NT	NT	8.9	3.7	4\32	12.5	2	1	91	7\35	20	0.198
22	5A	1	140	112.5	1	0.7	NT	NT	-	-	-	-	-	-	-	-	-	-
23	5B	1	112	90	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
24	5C	1	130	107	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
25	6A	1	120	96.4	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
26	6B	1	121	97.2	1	0.8	NT	NT	-	-	-	-	-	-	-	-	-	-
27	6C	1	136	109.2	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
28	7A	1	135	108.4	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
29	7B	1	149	119.7	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
30	7C	1	158	126.9	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
31	8A	1	140	112.4	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
32	8B	1	123	98.8	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
33	8C	1	122	98	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
34	9A	1	125	100.4	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
35	9B	1	114	91.6	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
36	9C	1	124	99.6	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
37	10A	1	134	107.6	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
38	10B	1	150	120.5	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
39	10C	1	134	110.3	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
40	11A	1	146	120.2	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
41	11B	1	156	125.3	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
42	11C	1	136	109.2	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
81	12A	2	106	73.3	15	14.2	NT	NT	-	-	-	-	-	-	-	-	-	-
82	12B	2	131	90.6	15	11.5	NT	NT	-	-	-	-	-	-	-	-	-	-
83	12C	2	97	67	12	12.4	NT	NT	-	-	-	-	-	-	-	-	-	-
84	13A-1	2	127	87.8	20	15.7	NT	NT	9	2.5	3\17	17.6	2	1	183	8\23	34.8	0.125
85	13A-2	2	151	104.4	23	15.2	NT	8.35	-	-	-	-	-	-	-	-	-	-
86	13A-3	2	103	71.2	9	8.7	NT	2.86	-	-	-	-	-	-	-	-	-	-
87	13B	2	123	85	16	13	NT	1.1	7	2.2	4\13	30.8	2	0	323	7\13	53.8	0.05
88	13C	2	104	71.9	18	17.3	NT	NT	7.7	3.3	6\12	50	1	2	191	8\22	36.4	0.117
89	14A-1	2	103	72.6	14	13.6	NT	NT	7.1	3.4	2\5	40	3	4	68	17\35	48.6	0.265
90	14A-2	2	134	97.3	11	8.2	NT	NT	-	-	-	-	-	-	-	-	-	-
91	14A-3	2	139	96.1	23	16.6	NT	NT	-	-	-	-	-	-	-	-	-	-
92	14B	2	93	64.3	12	12.9	NT	NT	7.5	3.5	4\9	44	1	2	67	17\35	48.6	0.269
93	14C	2	125	86.4	17	13.6	NT	5.12	8.4	2.9	6\13	46.2	2	5	83	22\35	62.9	0.157
94	15A-1	2	122	84.3	20	16.4	NT	3.05	6	2.6	8\18	44.4	0	1	150	14\28	50	0.117
95	15A-2	2	130	89.9	26	20	NT	2.48	-	-	-	-	-	-	-	-	-	-
96	15A-3	2	127	87.8	21	16.5	NT	3.61	-	-	-	-	-	-	-	-	-	-
97	15B	2	112	77.4	24	21.4	NT	NT	9.4	3.1	6\15	40	1	5	191	9\22	40.9	0.108
98	15C	2	109	75.3	19	17.4	NT	NT	8.7	2.7	7\15	46.7	2	2	175	11\24	45.8	0.108
99	16A	2	128	88.5	20	15.6	NT	0.98	-	-	-	-	-	-	-	-	-	-
100	16B	2	91	66	12	13.2	NT	0.98	-	-	-	-	-	-	-	-	-	-
101	16C	2	120	82.9	17	14.2	NT	0.43	-	-	-	-	-	-	-	-	-	-
110	17A	3	110	100.2	9	8.2	NT	8.92	-	-	-	-	-	-	-	-	-	-
111	17B	3	108	93.9	3	2.8	NT	3.87	-	-	-	-	-	-	-	-	-	-
112	17C	3	147	121.7	9	6.1	NT	2.97	-	-	-	-	-	-	-	-	-	-
144	18A	3	116	104.4	5	4.3	NT	NT	-	-	-	-	-	-	-	-	-	-
145	18B	3	115	114.2	4	3.5	NT	NT	-	-	-	-	-	-	-	-	-	-
146	18C	3	99	98.3	2	2	NT	NT	-	-	-	-	-	-	-	-	-	-

			Mussel Larvae				Microtox Assay		Sea Urchin Larvae Cytogenetic Analysis						Mussel Larvae Cytogenetic Analysis			
Sample #	Station #	Ref #	Total No. Larvae	Percent Survival	No. Abnormal	Percent Abnormal	Saline Extractions EC50*	Organic Extractions EC50**	Number of Mitoses per Embryo mean	Number of Mitoses per Embryo S D	# Telophases Aberrant \total	% Aberrant Telophases	Number Embryos with: >1 micronucleus	Number Embryos with: >1 cytologic abnormality	# Embryos evaluated\35 telophases^	# telophases (aberrant\ total)	% aberrant telophases	# Normal Telophases per Embryo
147	19A-1	3	99	86.1	6	6	NT	NT	10.2	4.5	34\59	57.6	6	10	124	23\34	67.6	0.092
148	19A-2	3	173	136.1	13	7.5	NT	NT	-	-	-	-	-	-	-	-	-	-
149	19A-3	3	120	99.3	12	10	NT	3.92	-	-	-	-	-	-	-	-	-	-
150	19B	3	100	86.9	8	8	NT	NT	5.9	2.6	23\33	69.7	6	4	145	15\29	51.7	0.117
151	19C	3	117	116.2	1	0.9	NT	NT	8.4	3.1	38\49	77.6	6	9	131	19\32	59.4	0.108
113	20A	3	135	111.8	11	8.2	NT	2.4	-	-	-	-	-	-	-	-	-	-
114	20B	3	125	108.7	13	10.4	NT	3.72	-	-	-	-	-	-	-	-	-	-
115	20C	3	75	74.5	3	4	NT	2.36	-	-	-	-	-	-	-	-	-	-
116	21A-1	3	151	137.5	8	5.3	NT	3.84	8.5	2.6	32\49	65.3	10	8	420	4\10	40	0.05
117	21A-2	3	143	124.3	12	8.4	NT	2.07	-	-	-	-	-	-	-	-	-	-
118	21A-3	3	145	126	6	4.1	NT	1.4	-	-	-	-	-	-	-	-	-	-
119	21B	3	126	120	8	6.3	NT	3.61	8.7	2.9	21\52	40.4	4	5	191	6\22	27.3	0.133
120	21C	3	109	99.3	5	4.6	NT	4.76	9.3	2.2	19\52	36.5	4	5	323	3\13	23.1	0.083
121	22A	3	156	135.6	16	10.3	NT	0.2	-	-	-	-	-	-	-	-	-	-
122	22B	3	104	103.3	5	4.8	NT	2.6	-	-	-	-	-	-	-	-	-	-
123	22C	3	139	138.1	7	5	NT	0.21	-	-	-	-	-	-	-	-	-	-
124	23A-1	3	118	112.3	10	8.5	NT	0.46	3.8	2.5	6\19	31.6	1	7	210	10\20	50	0.083
125	23A-2	3	142	123.5	9	6.3	NT	0.56	-	-	-	-	-	-	-	-	-	-
126	23A-3	3	130	123.8	2	1.5	NT	0.48	-	-	-	-	-	-	-	-	-	-
127	23B	3	140	133.3	6	4.3	NT	0.31	3.7	1.7	7\19	36.8	2	4	280	7\15	46.7	0.067
128	23C	3	133	126.6	11	8.3	NT	0.22	4.7	2.6	7\13	53.8	3	4	200	6\21	28.6	0.125
129	24A-1	3	133	126.6	8	6	NT	3.11	8.8	3.2	20\50	40	4	7	175	5\24	20.8	0.158
130	24A-2	3	127	131.4	8	6.3	NT	NT	-	-	-	-	-	-	-	-	-	-
131	24A-3	3	138	137.1	10	7.2	NT	NT	-	-	-	-	-	-	-	-	-	-
132	24B	3	73	69.5	1	1.4	NT	2.4	7.3	3.1	13\23	40.6	4	5	175	7\24	37.5	0.125
133	24C	3	117	125.9	9	7.7	NT	1.03	4.8	2.6	20\28	71.4	3	3	162	6\26	23.1	0.167
134	25A	3	125	119	6	4.8	NT	2.77	-	-	-	-	-	-	-	-	-	-
135	25B	3	168	146	21	12.5	NT	2.32	-	-	-	-	-	-	-	-	-	-
136	25C	3	120	109.3	9	7.5	NT	4.32	-	-	-	-	-	-	-	-	-	-
137	26A	3	108	107.3	9	8.3	NT	NT	-	-	-	-	-	-	-	-	-	-
138	26B	3	117	111.4	6	5.1	NT	NT	-	-	-	-	-	-	-	-	-	-
139	26C	3	115	104.7	12	10.4	NT	NT	-	-	-	-	-	-	-	-	-	-
140	27A	3	94	81.7	8	8.5	NT	3.18	-	-	-	-	-	-	-	-	-	-
141	27B	3	110	104.7	5	4.5	NT	7.39	-	-	-	-	-	-	-	-	-	-
142	27C	3	128	121.8	7	5.5	NT	3.33	-	-	-	-	-	-	-	-	-	-
152	28A	3	105	108.7	5	4.8	NT	NT	-	-	-	-	-	-	-	-	-	-
153	28B	3	134	133.1	10	7.5	NT	NT	-	-	-	-	-	-	-	-	-	-
154	28C	3	116	100.8	9	7.8	NT	NT	-	-	-	-	-	-	-	-	-	-
155	29A	3	126	114.7	10	7.9	NT	NT	-	-	-	-	-	-	-	-	-	-
156	29B	3	100	107.6	16	16	NT	NT	-	-	-	-	-	-	-	-	-	-
157	29C	3	84	90.4	7	8.3	NT	7.13	-	-	-	-	-	-	-	-	-	-
172	30A	3	81	73.8	10	12.4	NT	NT	-	-	-	-	-	-	-	-	-	-
173	30B	3	82	74.7	7	8.5	NT	NT	-	-	-	-	-	-	-	-	-	-
174	30C	3	114	108.5	16	14	NT	NT	-	-	-	-	-	-	-	-	-	-
158	31A-1	3	104	103.3	5	4.8	NT	NT	8.5	3.6	20\38	52.6	4	8	183	6\23	26.1	0.142
159	31A-2	3	78	71	7	9	NT	NT	-	-	-	-	-	-	-	-	-	-
160	31A-3	3	97	92.3	8	8.3	NT	NT	-	-	-	-	-	-	-	-	-	-
161	31B	3	87	86.4	12	13.8	NT	NT	11.4	3.3	9\55	16.4	2	2	168	6\25	24	0.158
162	31C	3	100	103.5	4	4	NT	NT	9.7	2	13\36	36.1	0	6	175	7\24	29.2	0.142
163	32A	3	68	64.7	4	5.9	NT	NT	-	-	-	-	-	-	-	-	-	-
164	32B	3	67	77.6	4	6	NT	10.2	-	-	-	-	-	-	-	-	-	-
165	32C	3	119	103.4	9	7.6	NT	NT	-	-	-	-	-	-	-	-	-	-
175	33A	3	111	96.5	8	7.2	NT	NT	-	-	-	-	-	-	-	-	-	-
176	33B	3	85	73.9	8	9.4	NT	NT	-	-	-	-	-	-	-	-	-	-
177	33C	3	91	94.2	11	12.1	NT	NT	-	-	-	-	-	-	-	-	-	-
178	34A	3	108	107.3	6	5.5	NT	NT	-	-	-	-	-	-	-	-	-	-
179	34B	3	136	146.4	14	10.3	NT	NT	-	-	-	-	-	-	-	-	-	-
180	34C	3	131	127.4	8	6.1	NT	4.7	-	-	-	-	-	-	-	-	-	-
184	35A	3	143	136.1	13	9.1	NT	NT	-	-	-	-	-	-	-	-	-	-
185	35B	3	113	102.3	11	9.7	NT	NT	-	-	-	-	-	-	-	-	-	-
186	35C	3	108	107.3	15	13.9	NT	2.3	-	-	-	-	-	-	-	-	-	-
181	36A	3	106	106.6	5	4.7	NT	NT	-	-	-	-	-	-	-	-	-	-
182	36B	3	108	107.3	3	2.8	NT	NT	-	-	-	-	-	-	-	-	-	-
183	36C	3	122	111.1	3	4.1	NT	NT	-	-	-	-	-	-	-	-	-	-
187	37A	3	123	112	9	7.3	NT	NT	-	-	-	-	-	-	-	-	-	-
188	37B	3	101	96.2	9	8.9	NT	NT	-	-	-	-	-	-	-	-	-	-
189	37C	3	129	128.1	6	4.7	NT	5.9	-	-	-	-	-	-	-	-	-	-

			Mussel Larvae				Microtox Assay		Sea Urchin Larvae Cytogenetic Analysis						Mussel Larvae Cytogenetic Analysis			
Sample #	Station #	Ref #	Total No. Larvae	Percent Survival	No. Abnormal	Percent Abnormal	Saline Extractions EC50*	Organic Extractions EC50**	Number of Mitoses per Embryo mean	Number of Mitoses per Embryo S.D	# Telophases Aberrant \total	% Aberrant Telophases	Number Embryos with: >1 micronucleus	Number Embryos with: >1 cytologic abnormality	# Embryos evaluated\35 telophases^	# telophases (aberrant\ total)	% aberrant telophases	# Normal Telophases per Embryo
166	38A	3	111	101	2	1.8	NT	NT	-	-	-	-	-	-	-	-	-	-
167	38B	3	78	61.3	10	12.8	NT	NT	-	-	-	-	-	-	-	-	-	-
168	38C	3	90	82	8	8.9	NT	NT	-	-	-	-	-	-	-	-	-	-
169	39A	3	95	86.5	10	10.5	NT	6.87	-	-	-	-	-	-	-	-	-	-
170	39B	3	91	79.1	7	7.7	NT	4.04	-	-	-	-	-	-	-	-	-	-
171	39C	3	104	99	3	2.9	NT	NT	-	-	-	-	-	-	-	-	-	-
43	40A	1	135	108.4	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
44	40B	1	137	110	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
45	40C	1	86	69	0	0	NT	3.04	-	-	-	-	-	-	-	-	-	-
46	41A-1	1	129	103.6	0	0	NT	1.41	10.6	3.7	7\32	21.9	0	0	168	10\25	40	0.125
102	41A-2	2	119	82.3	19	16	NT	NT	-	-	-	-	-	-	-	-	-	-
103	41A-3	2	121	83.6	28	23.1	NT	NT	-	-	-	-	-	-	-	-	-	-
47	41B	1	145	116.5	0	0	NT	0.78	9.5	4.3	5\24	20.8	0	1	150	14\28	50	0.117
48	41C	1	123	98.8	0	0	NT	2.04	7.3	3.5	7\22	31.8	0	2	155	13\27	48.1	0.117
49	42A-1	1	142	113.3	0	0	NT	0.59	7.5	2.9	5\20	25	0	2	106	7\35	20	0.264
104	42A-2	2	103	71.2	19	18.5	NT	NT	-	-	-	-	-	-	-	-	-	-
105	42A-3	2	139	96.1	22	15.8	NT	2.27	-	-	-	-	-	-	-	-	-	-
50	42B	1	152	122.1	0	0	NT	0.23	6.3	2.4	8\20	40	1	4	84	10\35	28.6	0.298
51	42C	1	136	109.2	0	0	NT	0.33	7.6	3.3	8\27	29.6	0	2	76	16\35	45.7	0.271
52	43A-1	1	146	117.3	0	0	NT	NT	9.4	3.3	6\22	27.3	1	1	70	16\35	45.7	0.271
106	43A-2	2	86	60.9	8	9.3	NT	NT	-	-	-	-	-	-	-	-	-	-
107	43A-3	2	139	96.1	10	7.2	NT	NT	-	-	-	-	-	-	-	-	-	-
53	43B	1	128	102.8	0	0	NT	NT	9.9	3.5	11\29	37.9	0	1	69	15\35	42.9	0.29
54	43C	1	161	131.8	0	0	NT	NT	8.5	3	5\24	20.8	1	0	68	13\35	37.1	0.324
55	44A	1	162	130.1	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
56	44B	1	148	118.9	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
57	44C	1	128	102.8	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
58	45A	1	161	129.3	0	0	NT	0.68	-	-	-	-	-	-	-	-	-	-
59	45B	1	138	110.8	0	0	NT	0.35	-	-	-	-	-	-	-	-	-	-
60	45C	1	126	101.2	1	0.8	NT	NT	-	-	-	-	-	-	-	-	-	-
15a	Ref 1	-	127	102	0	0	NT	NT	12.8	2.5	3\30	10	0	2	95	5\35	14.3	0.316
15b	Ref 1	-	132	106	1	0.8	NT	NT	10.9	3.7	3\44	6.8	0	2	82	3\35	8.6	0.39
15c	Ref 1	-	122	98	0	0	NT	NT	11.3	3.6	3\41	7.3	0	2	99	2\35	5.7	0.333
15d	Ref 1	-	137	110	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
15e	Ref 1	-	107	85.9	0	0	NT	NT	-	-	-	-	-	-	-	-	-	-
108a	Ref 2	-	101	69.8	11	10.9	NT	1.22	10.7	2.5	3\23	13	0	1	108	4\35	11.4	0.287
108b	Ref 2	-	98	67.7	13	13.3	NT	1.62	10.1	3.9	2\40	5	0	1	90	3\35	8.6	0.356
108c	Ref 2	-	110	76	9	8.2	NT	1.19	10.5	3.1	1\44	2.3	0	1	86	2\35	5.7	0.384
108d	Ref 2	-	113	78.1	11	9.7	NT	1.1	-	-	-	-	-	-	-	-	-	-
108e	Ref 2	-	103	71.2	11	10.7	NT	1.07	-	-	-	-	-	-	-	-	-	-
190a	Ref 3	-	106	114.1	7	6.6	NT	NT	11	2.9	2\35	5.7	0	2	89	1\35	2.9	0.382
190b	Ref 3	-	100	107.6	7	7	NT	NT	10.7	2.1	3\31	9.7	0	2	80	1\35	2.9	0.425
190c	Ref 3	-	99	106.5	4	4	NT	NT	11.1	3.5	3\39	7.7	0	4	79	3\35	8.6	0.405
190d	Ref 3	-	112	120.5	10	8.9	NT	NT	-	-	-	-	-	-	-	-	-	-
190e	Ref 3	-	108	116.2	8	7.4	NT	NT	-	-	-	-	-	-	-	-	-	-

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